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# **DEVELOPMENT OF SIMULATION SOFTWARE AND CALCULUS OF THE AUTOMATED GUIDED VEHICLES SWEEPS**

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**Development of simulation software and calculus of the automated  
guided vehicles sweeps at  
ASTI (Automatismos y Sistemas de Transporte Interno S.A.U.)**

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*I dedicate this work to the most important people in my life*

*For what they have taught me*

*For the unconditional support*

*For whom I am today*

*To my parents*

*To my family*

*To my friends*

## **Development of simulation and calculus of the automated guided vehicles sweeps**

### **Abstract**

In this era of technology growth, with the appearance of drones, vehicles that park by themselves automatically, submarines that drive autonomous, it starts to feel that the artificial intelligence is overcoming the human one.

The AGVs, automated guided vehicles, are continuously transforming the industrial environment. Although AGVs is one technology that came from the fiftys, it has just started to grow since the 21<sup>st</sup> century.

AGVs are normally used at industrial levels to transport big loads and/or to perform sequence of repetitive movements. The main functionality is to help companies save time, money and work.

The principal function of the AGVs is to support the factory workers on the hardest tasks such as towing, rising, pushing and forklifting loads, both at the warehouse logistics, internal and external transport as well as supporting the production lines.

These vehicles own an internal software, which controls the AGV movement with the help of sensors and strips. Some of these AGVs can communicate with a central computer to know its position and to receive orders from it, in order to either move or stop depending of the rest of the AGVs.

The purpose of this project is to acquire one software that be able to create routes for the different vehicles of any company, showing the exact sweep of the vehicles and their trailers to the user. It is also importat to avoid collisions with other areas in the factory layout, as well as to generate a precise route in order. This accuracy in the route is crucial, in order to achieve client satisfaction, as well as to facilitate the job of the technicians when they are placing the strip on the clients plant.

## Development of simulation and calculus of the automated guided vehicles sweeps

### Resumo

Neste período de grande crescimento tecnológico, com o aparecimento de drones, de veículos a estacionar automaticamente, submarinos que se conduzem autonomamente, começa-se a sentir que o período de sobreposição da inteligência artificial face à humana estará cada vez mais próximo.

Os veículos guiados automaticamente têm vindo cada vez mais a transformar o ambiente industrial. Estes veículos normalmente denominados por AGVs, sigla que vem do termo inglês, *Automated Guided Vehicles*, é uma tecnologia que já vem dos anos 50, mas só a partir do século 21 é que começou realmente a crescer.

Os AGVs, são especialmente utilizados a nível industrial para movimentar grandes cargas e/ou para fazer sequências de movimentos repetitivos e têm como principal função ajudar as empresas a poupar tempo, dinheiro e trabalho.

A função central dos AGVs é auxiliar os operários da fábrica em tarefas mais complicadas como: rebocar, elevar, empurrar e empilhar cargas, tanto a nível logístico de armazenamento e de transporte a nível interno e externo da fábrica, bem como a nível de auxiliar de linhas de produção.

Estes veículos possuem um software interno, o qual com a assistência de sensores e bandas controlam o seu movimento. Por sua vez alguns destes AGVs poderão comunicar com um computador central para conhecerem a sua posição, o qual analisando as diferentes posições dos restantes AGVs indicará a cada um a sequência de tarefas a efectuar.

Este projecto teve como finalidade de adquirir um software capaz de criar rotas para os diversos veículos de uma dada empresa, sabendo exactamente por onde passa cada parte do veículo e seus reboques de modo a evitar zonas de conflito com outras zonas da fábrica, bem como gerar uma rota mais precisa de modo tanto a satisfazer o cliente em questão, bem como de facilitar a tarefa aos operários que têm que representar esta rota no solo de cada fábrica.

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## **Acronyms**

AC	– Alternative Current
AGV	– Automated Guided Vehicle
ASTI	– Automatismos y Sistemas de Transporte Interno
CAD	– Computer Aided Design
DC	– Direct Current
FI	– Frequency Inverter
FIFO	– First In First Out
M	– Motor
PLC	– Programmable Logic Controller
QR	– Quick Response
RFID	– Radio Frequency Identification
SIGAT	– Sistema Integrado de Gestão da ASTI Tecnisoft
SAD	– System application designer
VAD	– Vehicle Application Designer
VDT	– Vehicle diagnostic tool

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# 1 Introduction

## 1.1 Problem objective

The main objective of this project was to understand the behaviour of different vehicles cinematic configurations and to develop a software system based on CAD technology to allow the modelling and simulation of different automatic vehicles sweeps along the plant layout, in order to study possible collisions. (Xidias, Nearchou & Aspragathos, 2009)

## 1.2 Project definition

One of the problems of defining a route in a factory layout is to understand the behaviour of the vehicle that will perform the route. The definition of the route will generate a specific movement of the vehicle and the variation on the speed will generate different kinds of trajectories. In this project it is important to simulate the path that a vehicle will perform in order to check the possible occurrence of collisions and to specify the appropriate speed to perform the movement, especially in the curves.

Although there are countless types of vehicles (Savant Automation, 2014), in this project there will be considered only two types, the simple and the compound vehicles. The simple vehicles are similar to cars, with a motor unit, where the direction of the movement is defined. Compound vehicles are considered as simple vehicles with trailers.

In order to maximize the AGV float efficiency and effectiveness on their transportation tasks, it is very important to design and optimize the plant layout, the routes and to efficiently define the sweep calculus of the AGVs and their trolleys.

## 1.3 Methodological approach

First, there was the need to study and understand the different types of vehicles and their configurations in order to comprehend their cinematic behaviour.

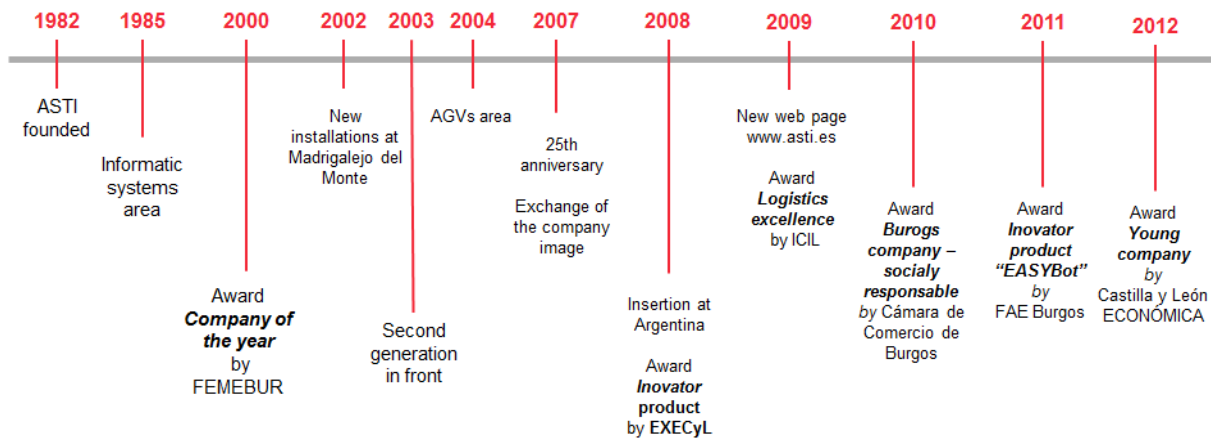
Next step was to learn about commercial software integrating CAD algorithms along with a variety of parameters that were evaluated and selected. The evaluation was based on the simulation of one vehicle and its trolleys sweeps along an established route. It was selected a group of vehicles that would be simulated in the chosen program. In the end the selected software was tested with a group of different vehicles and its trolleys. In the end, the improvements achieved by the program were studied.

## 1.4 The context of the project: ASTI

ASTI is a family company from Burgos, founded in 1982 and dedicated to the study of internal logistics engineering solutions (ASTI, 2014).

The company is constituted by more than 80% of engineers and high qualified technical personnel. The activities of ASTI are of a great variety, from the problem analysis in management, internal logistics and in the pack up, to the manufacturing of the designed solutions, as well as all the installation and maintenance services.

The vision of ASTI is “Ser un Referente Mundial, en el suministro de soluciones de automatización y sistematización de logística interna”, which means, to be a world reference in the implementation of automated and systematized solutions of internal logistics.



**Figure 1 - ASTI history**

So if we analyse this company history, it can be seen that the first generation had one idea of creating a good company since 1982. The new generation in addition to that, wants the internationalization of the company. As it is shown at 2008, they open a commercial office at Argentina and the website also helps in this internationalization (2009). From the timeline it is also notable the amount of awards that the company have received so far.



**Figure 2 - Organization chart**

In the Figure 2, it's the organization chart of the company ASTI. This project was developed at I+D+i (Investigation, Development and Innovation) department.

## **1.5 Thesis layout**

This thesis is divided in the following main chapters:

### **Introduction:**

In this section it is defined the problem objective of this project, what the project consisted and how it was approached. It was also given a brief presentation of the company where the project took place.

### **Literature review:**

This part of the project consisted in the studies realized prior the development of the project. The main features that are explained, is the composition and how works an AGV, analyzing which type of vehicles can be simulated and in the end, the explanation of the previous software program that the company owns.

### **Project development:**

The project development, as it name says, it is the section where is explained all the process for develop this project, in order to be able to produce results for the project.

### **Results:**

At the results section, it is explained the data, documentation and features created for the company.

### **Analysis and Discussion:**

This section is all about the advantages and disadvantages of the project. Showing how it improves project development of the company.

### **Conclusions:**

The conclusions of this project are explained in this section. In here it is analyzed the entire project and what it was achieved with it.

### **Future research:**

In the last chapter of this thesis, it is explained some of the extra features that can be created in order to improve the project at the company.



## 2 Literature review

### 2.1 Automated guided vehicles

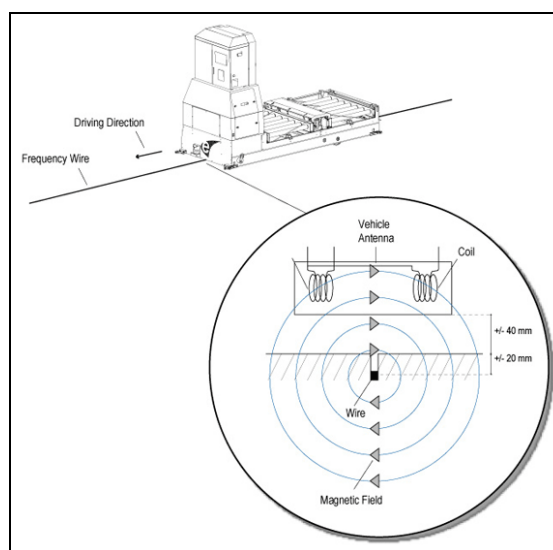
The base of this project is the study of sweeps of automated guided vehicles, also known as AGVs (Berman, Schechtman, & Edan, 2008). This type of vehicles appeared in 1953 as Savant Automation (2014) explains.

Let's explain first what is an AGV, how does it work and why it is important to study its sweeps.

In simple terms, an AGV is a vehicle that is automatically driven by itself without the necessity of human interaction. Since human interaction is not required, a group of sensors to drive through the plant of the factory is essential (Savant Automation, 2011). There are several ways to the vehicle to control the direction in an AGV, below is the list of the most common ones:

- Wired
- Guide tape
  - Magnetic
  - Coloured
- Laser target navigation
- Dual (Magnetic guide tape & Laser target navigation)

According to the layout, the wired system is placed on the floor, which serves as a trajectory for the AGV to follow. This wire will transmit a radio frequency (magnetic field) to the sensor installed at the bottom of the AGV and the AGV will follow the wire signal.



**Figure 3 - Wired system – adapted from**  
<http://www.fernandezantonio.com.ar/documentos%5CDoc%203%20Puentes%20Grua.pdf>

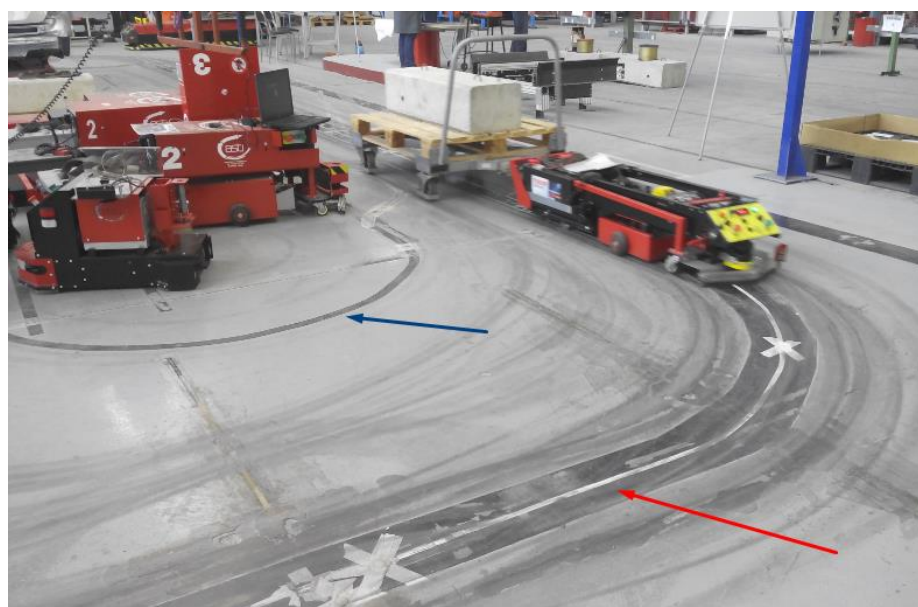
The wired systems have some positive and negative features. The chance of system damage is low due to the installation location, which is underneath the floor. On the other hand, there is difficulty in editing the route and the cost is high.



**Figure 4 - Wired sensor**

Referring to Figure 4, the wired sensor can follow 8 different frequencies (f1-f8), in this case: 5.1; 5.7; 6.3; 7.0; 7.8; 9.0; 10.0 and 12.0 kHz.

There are two types of guided tapes as shown above: magnetic or coloured. Both of them are placed on the top of the floor, which would make it easier to place and edit, but at same time easier to get damaged. Both tapes are indicated in Figure 5. The blue arrow points to the magnetic tape, and the red one to the coloured one. As you can see in the coloured one, a white and a black tape were utilized to, provide an easier job for the optical sensor to follow the white tape.

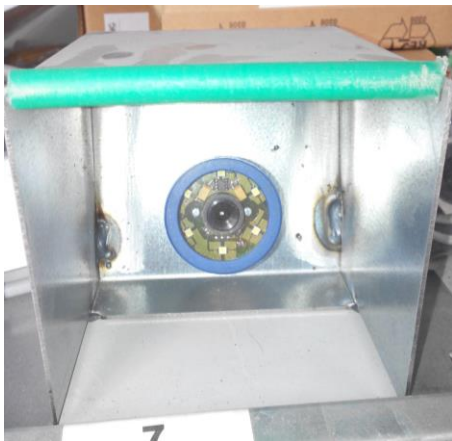


**Figure 5 - Guided tapes (magnetic and coloured)**

Since there are two types of tapes, we need two different sensors, a magnetic and an optical.



**Figure 6 - Magnetic sensor**

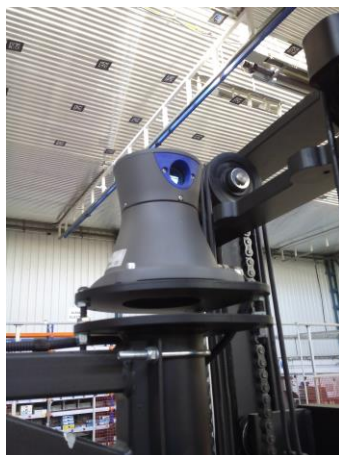


**Figure 7 - Optical sensor 1**



**Figure 8 - Optical sensor 2**

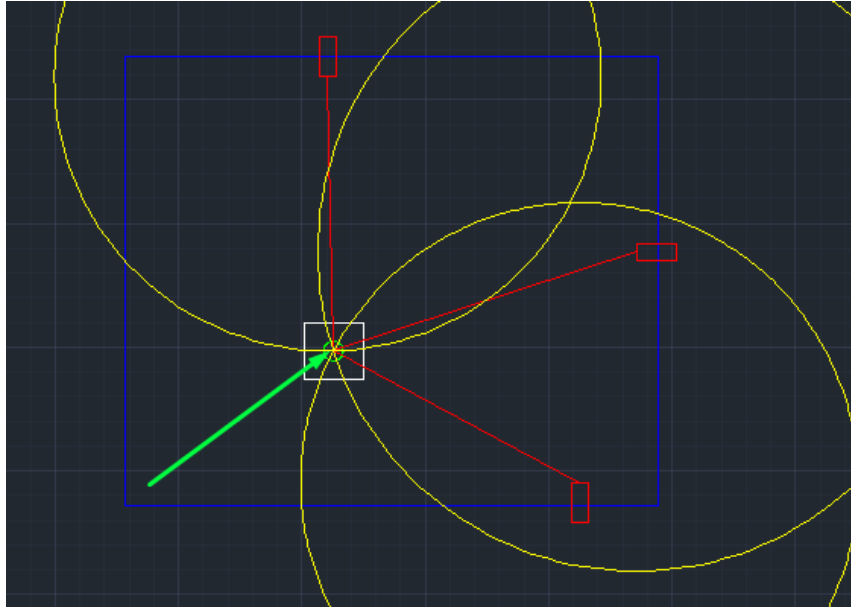
In the laser target navigation we equip the AGV with a rotating laser (transmitter and receiver) which is mounted in a turret. We fix some reflectors around the factory normally at walls and columns, and by triangulating the signal the position of the AGV could be identified. The AGV have a map of all the targets in its internal memory. The usage of the map is to correct its position error.



**Figure 9 - Laser transmitter/ receiver**



**Figure 10 - Reflector**



**Figure 11 - Triangular system example**

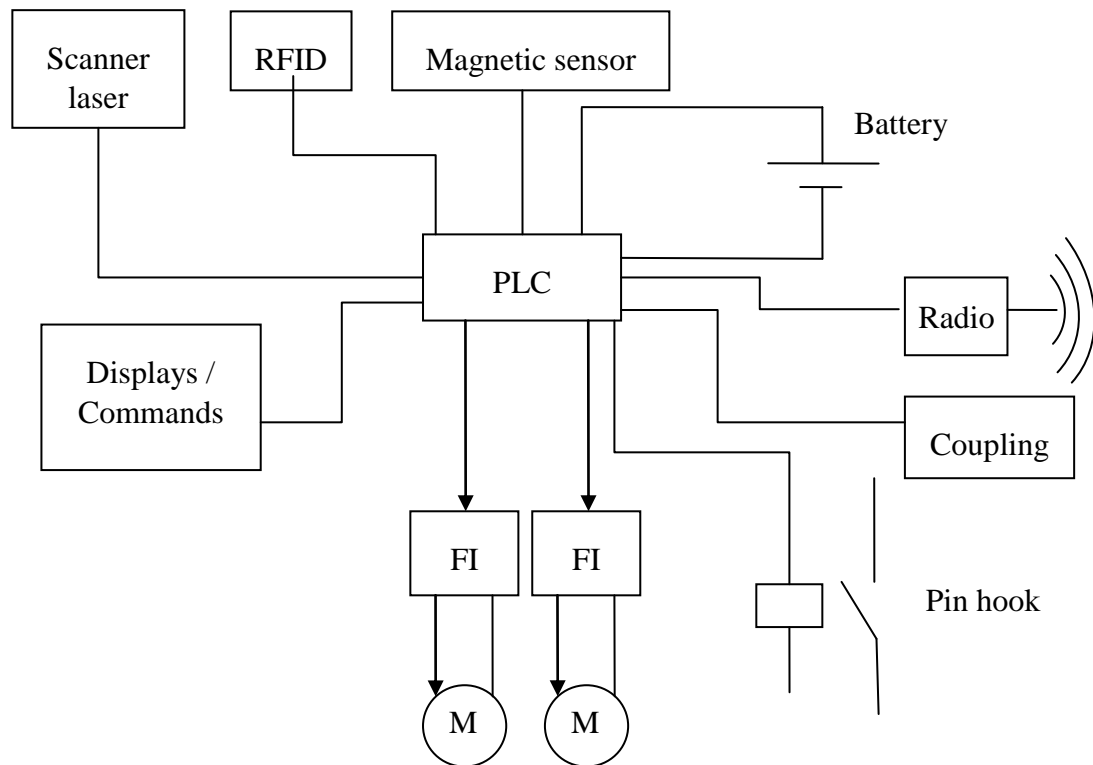
According to Figure 11, we could see an example of how the triangular system works in an AGV. The white square represents the AGV whereas the blue one represents the walls of the factory. The red rectangles represent the reflectors, and the red lines represent the laser that comes out of the laser transmitter/receiver of the AGV. So by knowing the distance from each reflector to the AGV, we could make three circles around each reflector to indicate the joining point. The joining point of the three circles indicates the position of the AGV.

Furthermore, there are other ways of location indication for the vehicle.

- Inertial (Gyroscopic) navigation
- Magnets
- Optical camera (QR codification on the roof)
- Optical reflector (Floor)

The inertial (Gyroscopic) navigation is not yet in use. The magnets, optical camera (QR codification on the roof), and optical reflector (Floor) had been used in the past, however, the accuracy is low.

Now that we understand how an AGV navigates, let's explain the rest of an AGV. Please see the diagram in Figure 12 for an easier and better understanding of the AGV.



**Figure 12 - AGV structure**

The PLC (programmable logic controller) is the brain of the AGV. All control functions come from the PLC, which are defined by the users and the AGV must perform.

From the PLC goes tension to the frequency inverter (FI), depending of the tension it performs different types of movement. The necessity of having this component is because the tension from PLC is direct current (DC) and the motor can only receive alternative current (AC).

In Table 1 is an example of how it performs.

**Table 1 - Variation of tension and it's perform on the motor**

<i>0V</i>	<i>0-2.5V</i>	<i>2.5V</i>	<i>2.5-5V</i>	<i>5V</i>
Full speed backwards	Variation from stop to full speed backwards	Motor stops	Variation from stop to full speed forwards	Full speed forwards

There is a frequency inverter for each motor. Nevertheless, if the two motors perform the same movement at the same time, the frequency inverter for both motors would be the same. This happens for example in the case below.



**Figure 13 - Two tier - two motor 1**



**Figure 14 - Two tier - two motor 2**



**Figure 15 - Four tier - four motors**

Figure 15 shows one motor for each wheel, due to the insufficient space for a unique and bigger motor for both wheels.

So far we know that we have one frequency inverter for each side and in each side we can have one or two wheels. This decision to have two or four wheels is just a question about how much power the AGV can carry.






**Table 2 - Number of wheels on tractor unit**

<b>Number of wheels</b>	<b>2</b>	<b>4</b>
<b>Power able to carry (N)</b>	250	400

Please note that a vehicle can have different types of wheels, and that they can have different placements. First let's analyse the type of wheels that a vehicle can have and what are its function.



**Table 3 - Type of wheels**

<b>Image</b>	<b>Name</b>	<b>Function</b>
 <p><b>Figure 16 - Fixed wheel</b></p>	Fixed wheels	Support vehicle weight; Avoid the vehicle to uncontrollable behaviour.
 <p><b>Figure 17 - Free wheel</b></p>	Free wheels	Support vehicle weight.
 <p><b>Figure 18 - Drive wheels</b></p>	Drive wheels	To generate the movement of the vehicle.
 <p><b>Figure 19 - Steer/Drive wheel</b></p>	Steering wheels	To generate direction in the movement of the vehicle.
	Steer/Drive wheels	To generate direction and movement of the vehicle.
 <p><b>Figure 20 - Omnidirectional wheel</b></p>	Omnidirectional wheels	To generate direction and movement of the vehicle.

At Figure 19, these wheels can be either steering wheels or steer/drive wheels. When they are steering wheels the vehicle has some drive wheels to generate the movement of the vehicle.

Until now we have already known what generates the movement of the AGV and how the route is directed. Now let's see how an AGV knows what to do in each position.

There are two types of systems:

- RFID system
- Information system via wireless to a computer

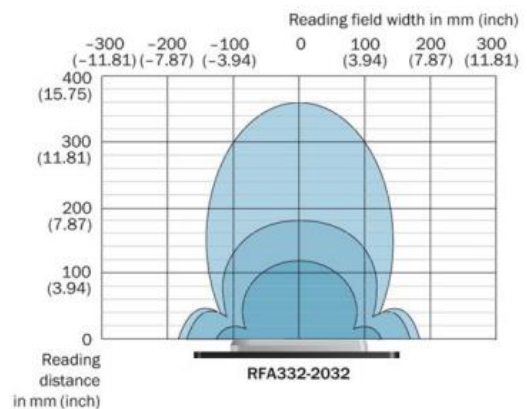
The RFID system, also known as radio-frequency identification, is a method that identifies an item using radio waves. The basic function of this system is that the vehicle has one RFID reader that will read RFID tags. These tags have some digital information that will be transmitted to the RFID reader and from this to the AGV. There are a big variety of RFID readers and tags. (RFID Journal, 2008)

Basically we have an RFID reader that reads tags along the path. Each tag gives information to the AGV regarding the tasks, such as:

- Stop
- Move at a certain velocity
- Raise or lower the pin hook
- Communicate with computer
  - Check if an AGV could move or wait for other AGV moves
  - Send notification upon arrival at a selected position
- Check the battery to see if it need to charge
- Scanner area



**Figure 21 - RFID reader 1 – adapted from <http://www.directindustry.com/prod/sick/rfid-reader-writers-integrated-antenna-894-553760.html>**



**Figure 22 - RFID reader – reading area – adapted from <https://www.mysick.com/PDF/Create.aspx?ProductID=77049&Culture=en-US>**

In Figure 22, since the tags are placed on the floor and the RFID reader does not have a big altitude to read the tag, they are placed in the bottom of the AGV; please refer to Figure 23.

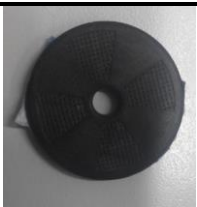

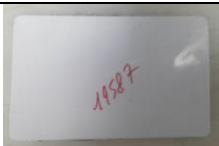





**Figure 23 - RFID reader 2**

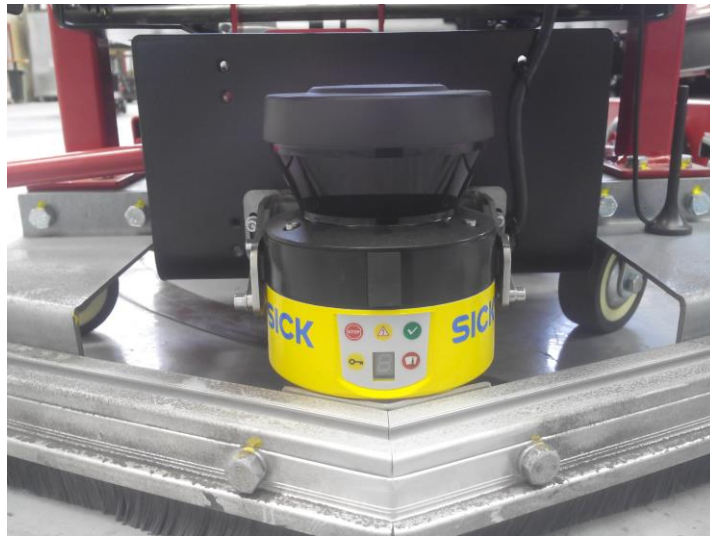
There are a big variety of RFID tags. The tags are placed on the floor in the positions where the RFID reader on the AGV passes by. In the Table 4 there is an example list.

**Table 4 - Different types of tags**

Image	Model name	Measures	Advantages	Disadvantages
 <p><b>Figure 24 - Disk tag</b></p>	Disk transponder	Radius=30mm Depth=1mm	Easy to change position; Can be fixed	Can be damaged
 <p><b>Figure 25 - Cylinder tag</b></p>	Cylinder transponder	Radius=20mm Depth=5.7mm	Protected	Small area of radio; Fixed position
 <p><b>Figure 26 - ISO card tag</b></p>	ISO CARD transponder	Dimensions= 55x85mm Depth=1mm	Big area of radio; Easy to change position	Very big dimensions, easy to be damaged
 <p><b>Figure 27 - Coin tag</b></p>	Coin transponder	Radius =50mm Depth=1mm	Easy to change position; Adhesive surface (to fix on the floor)	Can be damaged

Whenever there is the necessity to a precise stop of the AGV, for example in the case of the AGV stops at an exactly position, instead of using a tag to make the AGV stop, it's better to add a laser to the AGV. When the AGV arrives to the workstation, there will be a reflector in there, when the laser of the AGV sends and receives the signal transmitted to the reflector, the AGV will perform the precise stop needed, which it can't be acquired when we use tags.

Another important thing to have in the AGV is the scanner laser. Its function is to scan the area around the AGV, so it doesn't collide with any object, wall or human being. They are normally inserted in front of the direction of the movement, so they can scan the area in front of them to make sure that the vehicle will not collide. As we saw before, the scanner area can be changed during the circuit when the RFID reader scans a tag. (SICK, 2014)



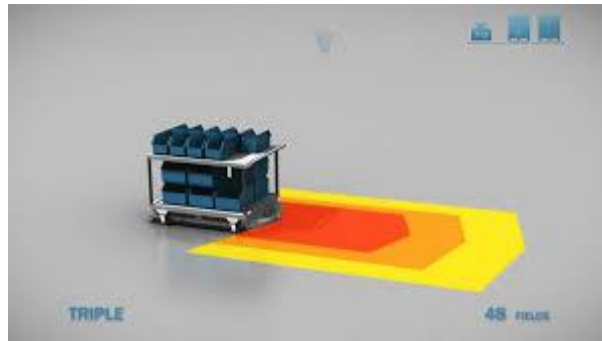
**Figure 28 - Scanner laser**

This area must change in two cases:

- Entering a corner;
- Entering a workstation

Entering the corner the laser must also see the inside of the corner, and when entering a workstation it must change the area so the AGV does not stop by detecting the workstation.

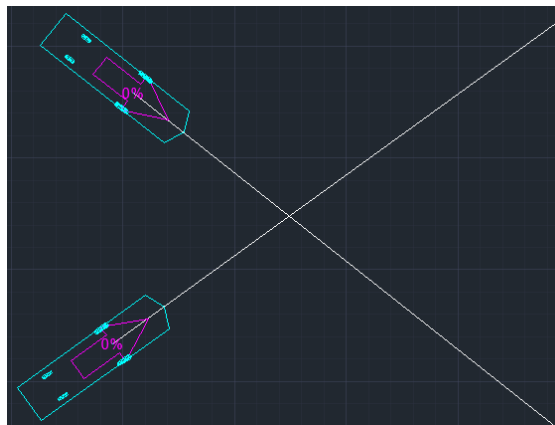
This scanner laser from Sick has 3 different zones, one for security and two for information. The security zone is the smaller area and it's to stop the vehicle if the scanner scans some "intruder". The information area 1 is a bit bigger than the security one and it's used to slower the AGV. The second information area is used to transmit a sound signal to the object that he finds. Please see Figure 29 for better understanding of this.



**Figure 29 - Scanner laser areas 1 – adapted from <https://www.youtube.com/watch?v=Lubzfam-ouk>**

- Red area - Security zone
- Orange area - Information area 1
- Yellow area - Information area 2

Now let's talk about the radio, the function of the radio it's to communicate with the central computer. This communication is used for example when there are two AGVs and their route crosses one another, like Figure 30. To decide which AGV goes first, normally it's decided as the FIFO method, (first in first out) and for that it asks the computer which one has permission to move first. (Klimn, Gawrilow, Möhting, & Stenzel, 2008)



**Figure 30 - Intersection problem**



**Figure 31 - Radio**



**Figure 32 - Radio antenna**

The display/commands it's where we have the human machine interface. Let's analyse one vehicle for example, the ASTI Easybot standard. In this vehicle we have 3 human machine interfaces. First we have the main interface: Figure 33.

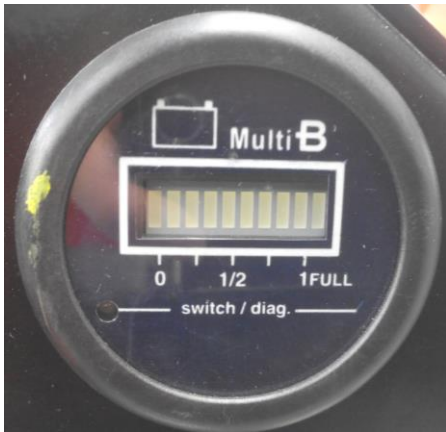


**Figure 33 - Easybot main interface**

In the main interface we have:

- Turn on/off selector (OFF/ON)
- Display codes (CODES DEFAULTS)
  - Errors;
  - Readings from sensors;
  - Movements;
  - Communications;
- Start button
- Emergency stop button
- Display lights
  - Working
  - Error
- SIGAT – transfer code to the AGV
- Manual control (C. MANUELLE) – manually control the AGV
- Entry/Exist (E/S) – add extra displays or commands to the AGV
- External commands (C.EXTERNES)
  - add another emergency stop button more accessible

Other displays that we have are the battery level and a charger indicator.



**Figure 34 - Battery level indicator**



**Figure 35 - Battery charging indicator**

The battery level indicator just works when the AGV is turned on and informs the user about the level of the battery.

To charge the battery it is needed to unplug the battery from the AGV. By doing this we cannot check the battery level indicator and for that reason, is used the Battery charging indicator. The Battery charging indicator will show up to three colours. It will show a red colour when the battery is low and the charging is starting. A yellow light will be displayed when the battery level reached 80%. And it will turn green when the batteries are fully charged.



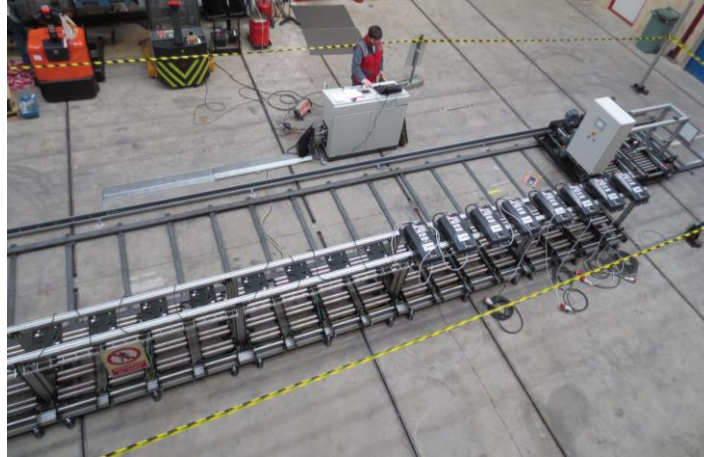
**Figure 36 - Charging battery**

The batteries are what give the energy to the AGV to perform all its tasks. The AGVs can work at least 8 hours, some can work 16 hours without charging, all depends on the size, work, speed and carry weight that the AGV is forced to.

For this reason, if we have a factory that works 24h/day we need to have some way to change the battery of the AGVs. In some AGVs we can have the possibility to do it automatically, but in other cases we need to do it manually.



In the automatic mode the AGV position itself next to the interchanger, an electromagnet gets the battery and places it in a platform. The interchanger moves itself to be able to insert the charged battery on the AGV and with the help of an electromagnet it places on the AGV. After this, the platform will move to the charging platform and insert there the uncharged battery so it can be charged. At Figure 37 we have the 8 battery chargers and in front of it we have the transporter platform.



**Figure 37 - Automatic battery charger & transporter platform 1**



**Figure 38 - Automatic battery charger & transporter platform 2**

At Figure 38 we can see the wheels that move the transporter platform and the two electromagnets, one of the platform will carry the charged battery and the other the uncharged one.

Other AGVs, which do not have this possibility to have the automatic interchanger of battery, the personnel will have to do it manually, for that there are some battery trolleys. In the Figure 39 and Figure 40, there are two example of it, one for each different type of AGV.



**Figure 39 - Manual battery charger 1**



**Figure 40 - Manual battery charger 2**

In these cases the personnel needs to move the battery to a spot where there is the battery charger.

**Note:** this charger can be inserted inside of the AGV, if there is no need to the AGV to be always running, in other words, if it can be stopped to be charging. In both cases it's the same charger and it is shown at Figure 41.



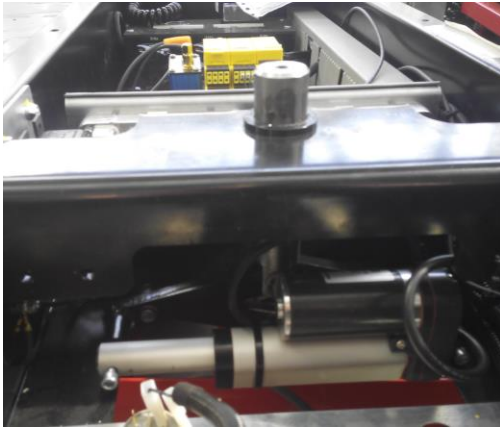
**Figure 41 - Battery charger**

The connection of cars and trailers in an AGV is one of the parts that were important for the study in this project. Please note that not all AGVs can take cars and trailers, some just have a pair of forks and carry pallets. In other cases we have some AGVs that are omnidirectional that basically is a platform that can move in any direction.

Some AGVs can take both cars and trailers, in this project it was studied the Easybot Standard that have this possibility, other vehicles can just carry trailers, what was the case of the Easybot Basic.

The Easybot Standard has a pin hook in the front of it and a coupling in the back. The pin hook in this vehicle is used to transport cars and the coupling unit is to transport the trailer.

This AGV has one relay that is connected to a motor and this to a worm screw that will perform the mechanical action of raising and lowering the pin hook.



**Figure 42 - Pin hook lowered**

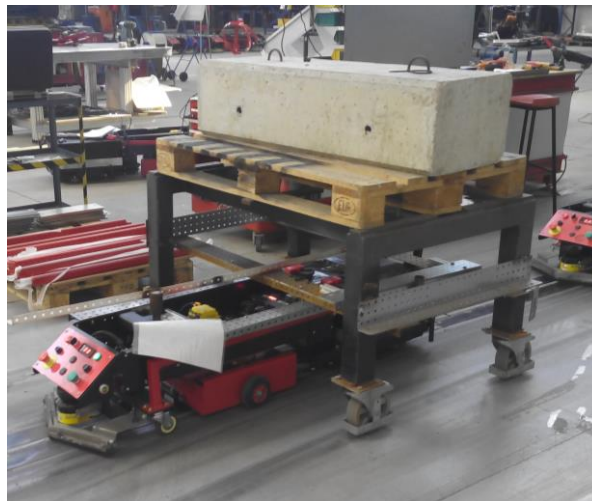


**Figure 43 - Pin hook raised**

The black cylinder is the motor, and below it is the worm screw, the grey cylinder. When the pin hook rises it is able to connect with the car. The car can have its wheels in two different types:

- All wheels free and connected in the pin hook and at other two points in the AGV
- All free wheels and two fixed wheels in the same line where the AGV have the fixed wheels

By doing this, the car and the AGV will have the same behavior in the movement and because of that it can be considered as a bigger AGV, as seen at Figure 44.



**Figure 44 - Car being carried by one Easybot standard**

Now to carry a trailer, the Easybot Standard has one coupling unit in the back of it. This coupling unit has a fixed position, as shown at Figure 45.





**Figure 45 - Easybot coupling unit**



**Figure 46 - Easybot carrying a trailer**

In an Easybot Basic there is just a pin hook in the back, meaning that only a trailer can be coupled.



**Figure 47 - Easybot Basic pin hook**

This pin hook has two ways to connect with the trailer, in Figure 47 it can raise and connect in the top. If we change the screw to the top whole, it can connect in the bottom like an Easybot Standard.

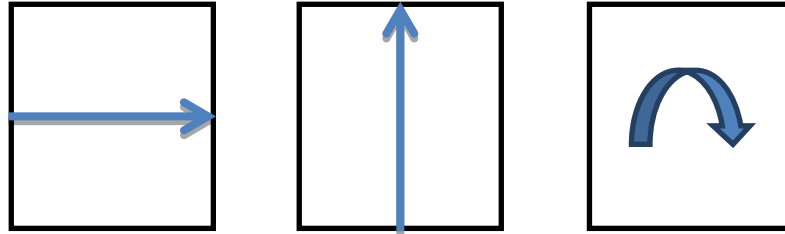
## **2.2 Holonomic and nonholomic system**

When we speak about AGV sweeps, we are not talking about what an AGV does when we give it a brush. What we mean is the study of the movement of each points of the vehicle when it describes one trajectory. Now this calculus can be made with different applications, but until we arrive to them, there have been a lot of historical steps. Let's start from the beginning.

One AGV behaves in a similar way as a car; in fact both of them belong to the group of a nonholonomic system. For better understand this, let's explain what a holonomic system is. If we consider a solid, that all the connections of its particles are strong and when this object moves, all the particles inside of the object does not change its position internally like an omnidirectional vehicle, we are talking about a holonomic system. This vehicle is holonomic because the controllable degrees of freedom of it are equal to the total degrees of freedom; in

a two dimensional space we have three degrees of freedom, axis x, y and the rotation on the origin; this type of vehicles have this same behaviour.

On this vehicle the wheels can slide while the others rotate, so we can move in the three degrees of freedom, as it is shown in the Figure 48.



**Figure 48 - 2D holonomic movement system**

The ASTI Company has this type of vehicles and they name it as omnidirectional Easybot. These types of vehicles have a specific type of wheels not like the conventional one, which will allow doing all this types of movement. In the Figure 49 is an example of it.



**Figure 49 - Omnidirectional Easybot**

These vehicles have their wheels placed as shown at Figure 50 and the configuration of the wheels is displayed at Figure 20.



**Figure 50 - Positioning of the wheels at the omnidirectional Easybot**

But now going back to the example of a car or a tricycle, we do not have this type of behaviour, the components of the vehicle they move inside of the vehicle. For example when we perform a parallel parking on these vehicles, the front wheels move inside the vehicle. The entire vehicle components will perform different type of movements, internally, when it is not moving on a line.

### **2.3 Kollmorgen layout designer**

The first software program used was Kollmorgen layout designer. This software is just used by some types of vehicles, vehicles that use the Kollmorgen information system, but not all vehicles have this information system.

At ASTI, vehicles that used this software were called RoboFast. These vehicles were acquired by the company to an external provider and then the company transform these vehicles into full automated vehicles using Kollmorgen software programs. In additional it will also be added sensor lasers and laser transmitter/receiver for example.

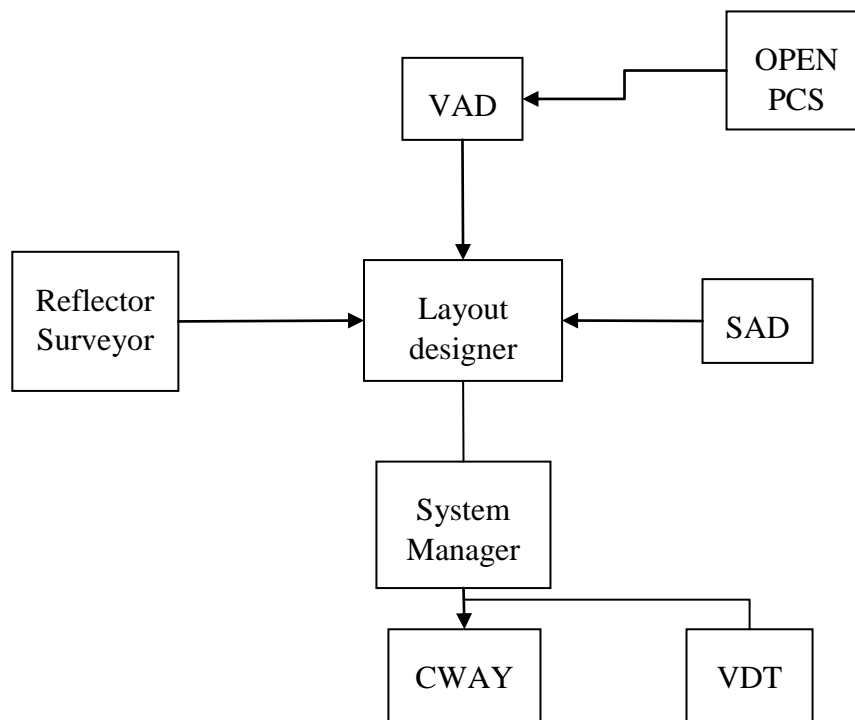
If this software does all of this, why do not we used it to calculate the vehicle sweeps of all the AGVs of the company? The main reason for this is because this software is not able to calculate vehicles with trailers and it is not able to run in a CAD system, which is the common software used to draw the client layout factories.

The layout designer, it's just one of the programs of the Kollmorgen and its function is to create the sweep paths of vehicles and check if they can have collisions or not with any structure at the factory. But in this program you cannot define the vehicle dimensions, for that you need VAD (vehicle application designer), which is a program that is made just for defining the vehicles.

Another software of Kollmorgen also used is the CWAY, which checks in real time where the vehicle is and shows two distinct colours to see if the vehicle is running well (green colour) or if the vehicle is broken (red colour).

All this programs communicate with each other, and they aren't the only these ones used, but for this project these are the ones that matter the most.

In the Figure 51 it's a scheme of how all the Kollmorgen software interact with one another.



**Figure 51 - Kollmorgen communication scheme**

Now it will be explained a bit about the software programs that are represented in the Figure 51.

- VAD - Vehicle Application Designer
- OPEN PCS - Program the AGV
- Layout designer - To draw the route
- Reflector surveyor - To place the reflectors position
- System Manager - Controls the orders of the AGVs
- SAD - System application designer
  - To define the task to do in each position
- CWAY - Controls in real time the AGVs (human interface)
- VDT - Vehicle diagnostic tool
  - To analyse the black box of the AGV

Analysing layout designer, it is a software that needs integration with other software programs. It cannot represent the sweeps of most of the company vehicles; we cannot add laser fields and predict where we have to place the tags. It is impossible to represent the typical Easybot Standard, that is one of the most requested AGV of the company and we cannot represent any trailers. Another problem is that we cannot define a specific shape of a vehicle, so we cannot have an accurate sweep simulation. For all these factors there was the need to incorporate a new program that would be able to do all this functions.

### 3 Project development

This project was developed at ASTI, for a period of 4.5 months. Table 5 shows the Gantt diagram with each task and its duration.

**Table 5 - Gantt diagram part 1**

<b>Task n°</b>	<b>Task</b>	<b>Duration</b>	<b>Beginning</b>	<b>End</b>	<b>Preceding</b>
1	Project presentation	5days	10/02/2014	14/02/2014	
2	Study of layout designer	5days	10/02/2014	14/02/2014	
3	Study of system requirements	5days	10/02/2014	14/02/2014	
4	Study of market solutions (Inventor, Autopath, Autoturn...)	5days	17/02/2014	21/02/2014	1, 2, 3
5	Search in the internet of market solutions	5days	24/02/2014	28/02/2014	4
6	Definition of project specifications	5days	24/02/2014	28/02/2014	4
7	Presentation of the project to the department managers	5days	03/03/2014	07/03/2014	5, 6
8	Parameterization of the EASYBOT vehicle	5days	10/03/2014	14/03/2014	7
9	Test of vehicle sweeps and simulations with the chosen tool	5days	17/03/2014	21/03/2014	8
10	Parameterization of a trailer connected with an EASYBOT	5days	24/03/2014	28/03/2014	9
11	Parameterization of the different points inside of an EASYBOT vehicle and its laser field	5days	31/03/2014	04/04/2014	10
12	Documentation of the project development	5days	07/04/2014	11/04/2014	11
13	Presentation to the department managers	5days	07/04/2014	11/04/2014	11
14	Holidays	5days	14/04/2014	18/04/2014	12,13
15	Corrections on the program	5days	21/04/2014	25/04/2014	14
16	Parameterization of different vehicles and trailers	15days	21/04/2014	13/06/2014	14
17	Presentation to the CEO and department managers	5days	12/05/2014	16/05/2014	16
18	Final tests, adjustments and improvements	20days	19/05/2014	13/06/2014	17

19	Project documentation	15days	26/05/2014	13/06/2014	
20	Presentation to the department managers	5days	09/06/2014	13/06/2014	
21	Corrections, final adjustments	10days	16/06/2014	27/06/2014	18, 19, 20
22	Formation to the ASTI team	5days	16/06/2014	20/06/2014	18, 19, 20
23	Final presentation with the results to the department managers	5days	23/06/2014	27/06/2014	22

In Annex E it can be viewed the full Gantt diagram.

The first period at ASTI was devoted to the study of the systems that ASTI uses, and to understand how they could be improved. Since the period of task number 4, it started the investigation of a new CAD software to simulate the sweep path of the vehicles that were not able to perform in the Kollmorgen software.

At task number 7 the best programs were selected and it started the testing of them, in order to understand which one was the best for the company. After selecting the best program it was important was to create as much vehicles as possible, so that ASTI would be able to easily select a vehicle and perform its sweep path analysis. After the creation of these vehicles it was also important to add specific points or areas in the vehicle. These points and areas were then used to simulate the path that the sensor laser would do, and to simulate where to place the tags in order that the RFID reader could read them. These were all extra features added to the software because they were important studies, and were not possible to be performed in the existing program prior the Autodesk Vehicle tracking.

After all of this, there was the necessity to create some documentation and videos in order to support ASTI users of this new software program. By doing these manuals, step by step, it was achieved one big step, reducing the execution time of any task with the program. These tasks consisted of creating a vehicle, placing tags in a route, defining a laser area until the real objective of this project and creating a sweep path analysis of the vehicles.

### 3.1 Comparing programs

Since there is the need to predict the path of a vehicle, there is a continuous development of software on this field. This kind of programs are starting to be used in the most distinct areas, such as the road vehicles, like cars, tractors with big trailers for example the ones that transport wind blades, or even airplanes. This kind of studies are important mostly for engineers, designers and planners at government agencies and engineering consulting firms to simulate the vehicles movement.



**Figure 52 - Tractor transporting wind blade**

By predicting the movement of a vehicle, we can reduce the risk of collision, check if a vehicle will be able to perform a certain route or even edit our layout so the vehicle can do a specific route.

There are only quite a few developers of this type of programs, and some design companies are starting to acquire this software and use them as plugins on their main programs like Autodesk.

Some of these software programs were studied, taking into account the most important parameters for the company. In Annex A the list of the most important parameters for this project are presented.

A search on the web, allowed to create a list of some available programs that were studied and compared:

- Autodesk vehicle tracking;
- AutoTurn 2D;
- AutoTurn 3D;
- Invision;
- Malz++Kassner;
- AutoTrack;
- Path Planner;

AutoTrack and Path Planner were automatically removed from the comparison, since the first one was acquired by Autodesk and was transformed in the Autodesk vehicle tracking, and the other one, Path Planner, was removed from the market since January 29, 2014.

Malz++Kassner is a German software and one of the main issues using this program, was the difficulty to work with it added to the fact that it was not compatible with the AutoCAD format. Hence, it was decided to leave this program out from our comparison.

In the end, we made a full comparison of the rest of the programs. The main difference between AutoTurn 2D and 3D was the fact that in the 3D we could create 3D vehicles and perform vertical analysis, which were not available on the 2D version.

The main function of Invision, was not to create sweep paths, but to combine simulations that were performed in AutoTurn 2D and 3D, so it was an extra software that was required by the parameters that were defined.

In the Autodesk vehicle tracking we have everything that AutoTurn 3D and Invision have and we can better define the mechanical characteristics of the vehicle, so it would simulate better the cinematic performance of the vehicle, which will create a better sweep path simulation.

In Table 6 it is presented a simplified list of the comparison, at Annex B we can see the full comparison.

**Table 6 - Simplified program comparison**

Criteria	Vehicle Tracking	Autoturn 3D
Handling	✓	✓
Vehicles and trailers	✓	✓
Paths	✓	✓
Integration with AutoCAD	✓	✓
Obstacles detection	✓	✓
Self Drive	✓	✓
Simulations in 2D and 3D	✓	✓
Precision	✓	✗
Cost (€)	1050+315 anual	2250

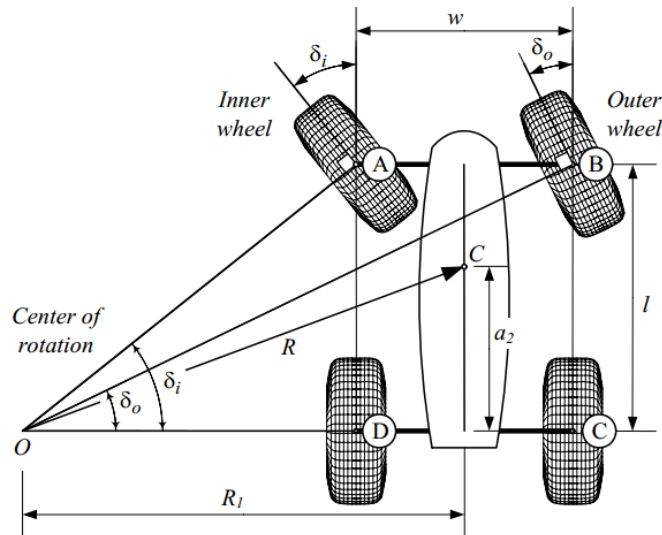
Even if in Autodesk vehicle tracking we have an annual cost and AutoTurn 3D it just needs one license without time limit, after comparing both software programs, we decided to go with Autodesk vehicle tracking since it gives a better precision, and it is a very important factor when calculating the sweeps of the vehicles.

### 3.2 Ackerman and differential wheels

All the software programs that were tested used vehicles with Ackerman wheels; these are the wheels that are used by cars. At this type of movement the vehicle inner wheel will have a bigger inclination then the outer wheel.

The Ackerman condition says: *“To have all wheels turning freely on a curved road, the normal line to the center of each tire-plane must intersect at a common point.”* as it is shown on the Figure 53. (Jazar, 2014)





**Figure 53 - Ackerman condition**

If the vehicles at the Autodesk vehicle tracking have this type of movement and, in the other hand, the vehicles that we could not create on Kollmorgen are differential vehicles; we have to adapt those vehicles to Ackerman's.

Let's see the example of the Easybot Standard. An image of one of these vehicles is displayed in the Figure 54.



**Figure 54 - Easybot Standard**

As we can see in the Figure 54, the AGV have 6 wheels. From front to back, we first have two free wheels, then we have two differential wheels and in the back a pair of fixed wheels. The function of the free wheels is just to support the weight of the AGV, so we just take into account the differential wheels and the fixed ones.

The differential wheels have one motor for each wheel, with two functions, to steer and drive. This vehicle as you can see, have a red metal box that connects these differential wheels to the rest of the AGV. So, basically this red box is the tractor unit of the AGV and we can consider the rest of the AGV as a trailer. Later, it will be explained why we made this analogy. when the AGV wants to perform a perfect line, it will give the same tension to the differential wheels, always taking into account if the following sensor (in this case the magnetic sensor) is following well the stripe on the floor (for a magnetic sensor we have a magnetic stripe). If the magnetic sensor starts to going out of the line, it means the vehicle is entering a curve line, so this sensor will communicate with the PLC, demanding it to give a different tension to each wheel in order to try to perform the right curvature. Since it cannot see the whole line, it will

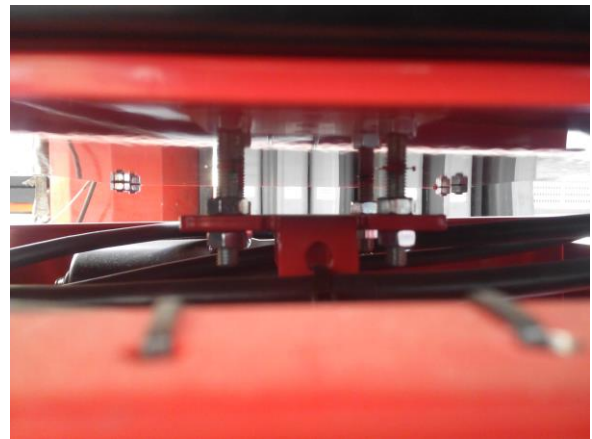
be always adjusting while it is in the corner, until it finds a straight line again and will give the same tension to both wheels.

As it can be seen, we have a completely different way to drive an Ackerman vehicle and a differential one. In order to surpass this obstacle, since the software only accepts Ackerman vehicles as tractor units, we considered the vehicle as made in two parts. of the first part is the tractor unit. Even if in the real life we only have 2 wheels in the Autodesk vehicle tracking we must have the 4 wheels, two directional and two fixed, so we made a tractor unit with 4 wheels with the width distance equal to the real life one (of the differential wheels) for both front and back wheels. Then the distance of front and back wheels were joined together so we just have the same behaviour as we had two differential wheels.

To create the rest of the AGV, we consider it as a trailer that was connected at the center of the axis of the tractor unit, and actually it is what occurs in the real life vehicle, even if we consider it as one vehicle with just one part. Figure 55 and Figure 56 represent it.



**Figure 55 - Tractor unit**

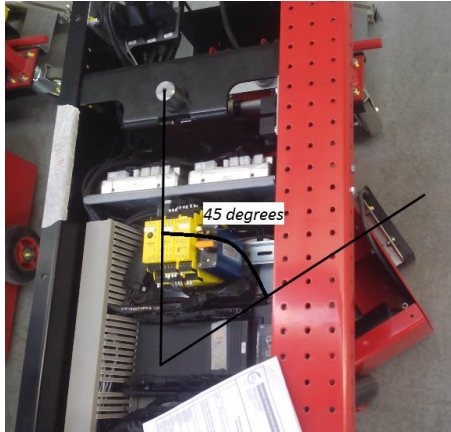


**Figure 56 - Connection from tractor unit to AGV**

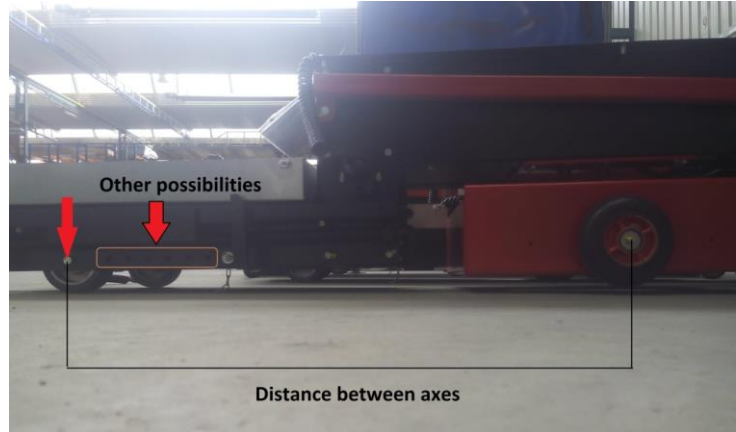
### **3.3 The right curvature**

After the adjustment of the AGV to an Ackerman vehicle, it was started the simulation of the AGV in the program. It was discovered that the simulated vehicle was not able to perform the same curves performed by the real vehicle. In an analysis to the simulated vehicle, the problem was found. The tractor unit created has the two front and back axis together and it was not accepted as a mechanical possibility. So, it was studied the minimum curve that the real AGV could perform.

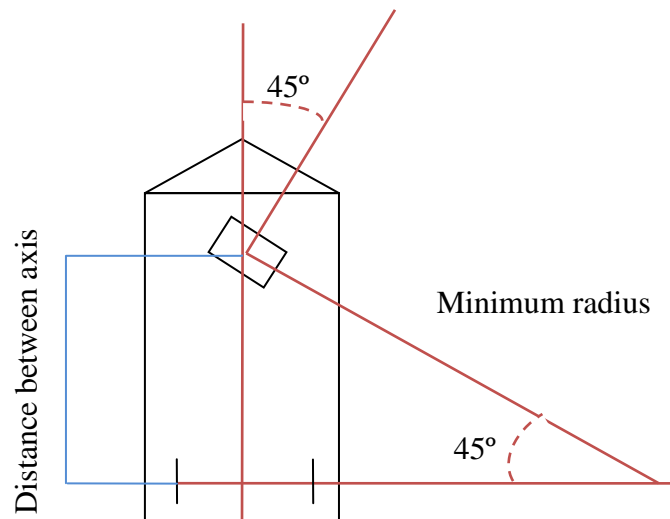
As shown at Figure 57, we calculated the maximum real angle that the vehicle was able to do and its value was  $45^\circ$  for each side. And by knowing the distance between axes (Figure 58), we were able to determine the center of rotation and the minimum radius.



**Figure 57 - Maximum angle of rotation of tractor unit**



**Figure 58 - Distance between axis**



**Figure 59 - Minimum radius calculus**

As we can see in Figure 59, we were able to determine the minimum radius of curvature from here. After editing the distance between axes of the tractor unit, we achieved the distance that we needed to perform the minimum radius curvature and with this we had our vehicle fully simulated.

$$\sin 45^\circ = \frac{\text{Distance between axis}}{\text{Minimum radius}}$$

$$\text{Minimum radius} = \frac{\text{Distance between axis}}{\sin 45^\circ}$$

**Table 7 - Data to calculate mininum radius**

Angle	Distance between axis	Minimum radius
45°	795mm	1124.3mm

### 3.4 Error between simulation and real life

After the full specification of the vehicle, there was the need to check the error between the real movement of the vehicle and the trajectory simulated in the software application.

We created a gadget to add to the vehicle and its trailer. This gadget was composed by some metal plates, steel tubes and screws, and by adding it to the vehicle and inserting one chalk in the tube with a steel cylinder to add some weight to it, the gadget draw the trajectory of one point of the vehicle.

Then we also added the same point to the simulated vehicle and made the simulated vehicle to follow the same path that the real vehicle performed.

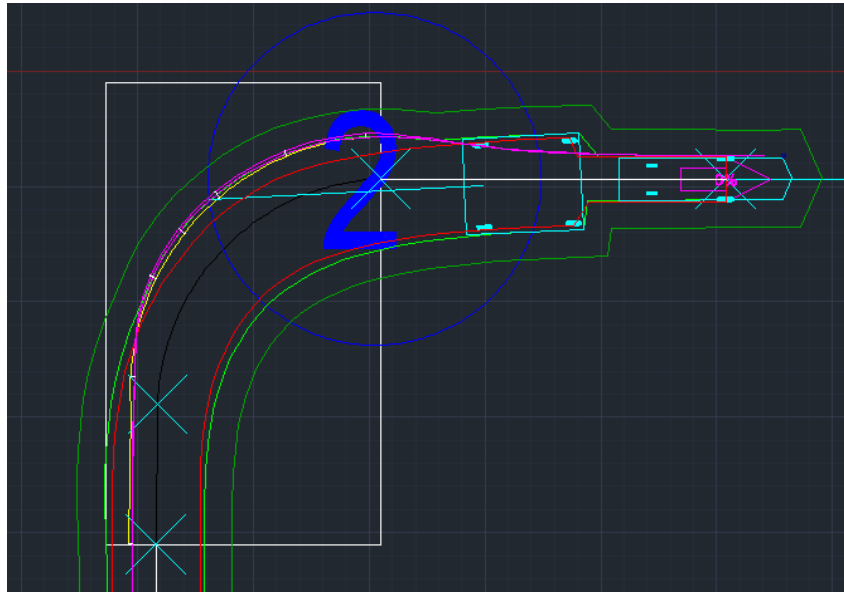
Figure 60 and Figure 61 show the gadget that was created and where it was placed.



**Figure 60 - Gadget for the AGV**



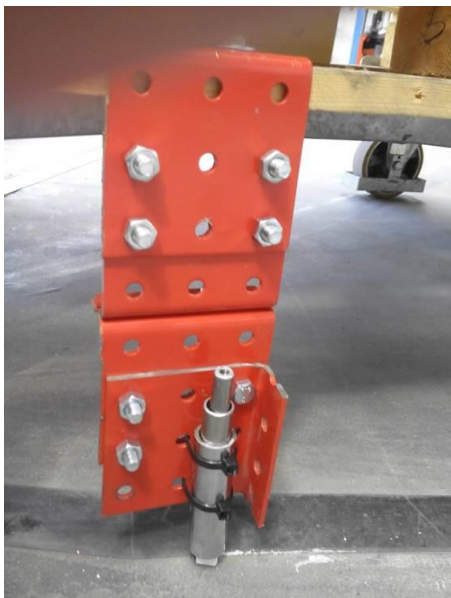
**Figure 61 - Path draw by the AGV gadget**



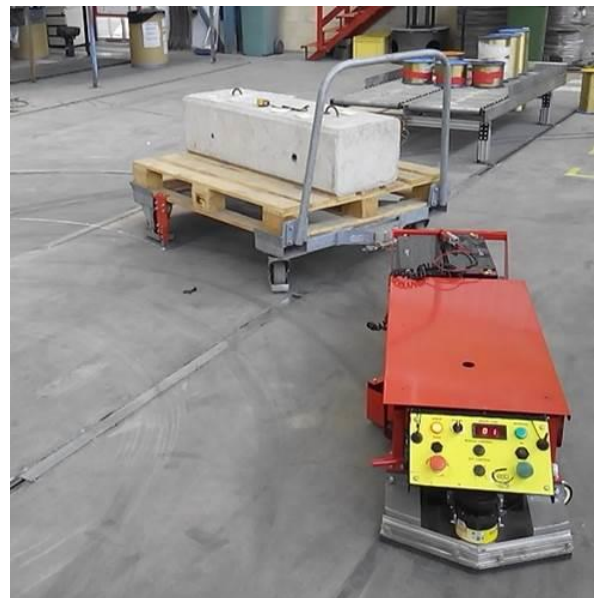
**Figure 62- Comparing simulation with real trajectory**

As it can be seen in the Figure 62, the purple line is the simulated line of the gadget and the yellow line is the real trajectory.

For the trailer, there was the necessity to adapt the gadget and it was inserted into two parts of the trailer, one on the left and the other on the right side of it. In the Figure 63 and Figure 64 it is shown the adapted gadget and the insertion of it in one side of the trailer.



**Figure 63 - Gadget for the trailer unit**



**Figure 64 - Path draw by the trailer gadget**



**Figure 65 - Simulation and real point analysis**

In Figure 65 we can see in the purple lines the trajectory done by the simulator, and the yellow dots represent where the chalk has passed in the real movement.

By calculating the error distance from simulation in relation to the real life, the biggest error was of 3cm what was very satisfactory, because it demonstrates a great precision.



## 4 Results

### 4.1 Creation of vehicles library

Since there is not a single AGV produced at ASTI, there was the necessity to create a list of vehicles, as big as possible, so we could simulate the paths for any vehicle. By measuring the vehicle dimensions and its behaviours, we were able to create almost all type of vehicles that the company produced, but some of those vehicles were not able to be used in simulation due to its strange configuration.

The vehicles that were not possible to create in the software were the Easybot bidirectional, Easybot omnidirectional and the Quad vehicle.

Let's explain why these vehicles were not able to be simulated in the software.

The bidirectional was not possible to be used in the Autodesk vehicle tracking, because it is an AGV with two different tractor units.



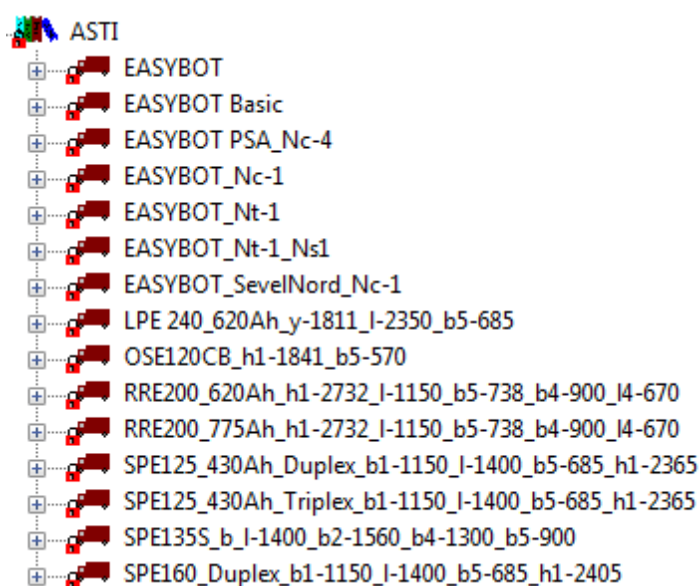
**Figure 66 - Easybot bidirectional**

As it can be seen at Figure 66, this vehicle has two tractor units, both of them follow the magnetic stripe. Since the same vehicle has two tractor units it does not move as the normal vehicles, like a car that only has one tractor unit. Since the vehicle has this behaviour it cannot be simulated as normal car, because this vehicle can do hardest curves that the normal vehicle cannot.

Now let's examine both Quad and Easybot omnidirectional. The problem of these vehicles in the simulation is that they are holonomic. As it was explained before, this vehicle can move in any directions and rotate by its center and that it is impossible to simulate in a normal car.

These are the reasons why these three vehicles cannot be simulated on the Autodesk vehicle tracking.

Even that these three vehicles cannot be simulated, all others can. In the Figure 67 it is the list of vehicles created in the Autodesk vehicle tracking.



**Figure 67 - Autodesk vehicle tracking - ASTI vehicle library**

Mainly there are two big classes of vehicles at ASTI, the Easybot and the RoboFast. The Easybot are vehicles that are fully developed by the company from its body layout to the programming. The RoboFast are vehicles that the company acquired and use Kollmorgen programs to program the vehicle.

In the list above, Figure 67, all Easybot start with EASYBOT name and then is specific characteristics. And the RoboFast have its first specific name first and then its characteristics. Both types of vehicles have characteristics that never change so and those are not specified on the name.

## 4.2 Creation of manuals and tutorials

During the project it was developed some documentation and videos, in order to support the Autodesk vehicle tracking users. The documentation consisted in two manuals; one of them is mainly about vehicle configuration and the other one about creating trajectories. The reason for creating two manuals instead of just one was by taking into account the final user of it; some users in the company will create vehicles, the mechanical department and the other users will be from the control and automation department and after sales.

It is easy to understand why the mechanical department will need the configuration vehicle manual, since they are the department that take care about drawing the vehicles and analyzing where each component of the vehicle must be inserted. The reasons for the other departments have the necessity to have the manual, is because these departments are the ones that study the route of the vehicle and that study where they have to place the tags and define sensor laser fields.

Let's make a brief description of each manual. Starting with the "Technical manual – Autodesk Vehicle tracking, Vehicle configuration". This manual explores the different ways to create a vehicle, by editing a copy of an existing vehicle or by creating a new one from the ground. The reason to edit a copy of a vehicle is that most of all the existing vehicles can be configured in distinct ways, for example an Easybot Standard the distance between axes can change (see Figure 58). In this manual, it is also explained how the nomenclature was done for each vehicle and the criteria to do it when a vehicle is edited or created.



The other manual, “Technical manual – Autodesk Vehicle tracking, Layout design”, is about how to create routes, place tags and sensor lasers. This manual will be used when the client provides the layout of the factory and with it, we can manage to create the sweep paths and tag placement. It also can be used the sensor laser areas so the AGV can move in a path without collisions.

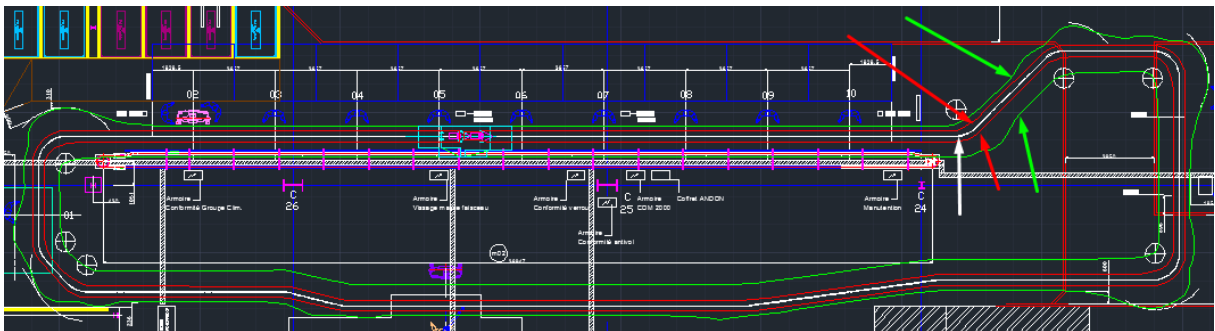
It was also created thirteen tutorial videos both in English and Spanish, explaining every feature of the Autodesk vehicle tracking program, so it would be much easier for any user to do any feature presented on each manual.

### 4.3 Creation of paths

During the project some studies to clients were executed, in order to understand the path generated by the vehicle.

In some projects there was the problem that the vehicle route, defined by the client, was impossible to be executed, so it was asked to the client where the vehicle should be able to pass. Then, by adjusting the route, the vehicle was able to follow the path defined.

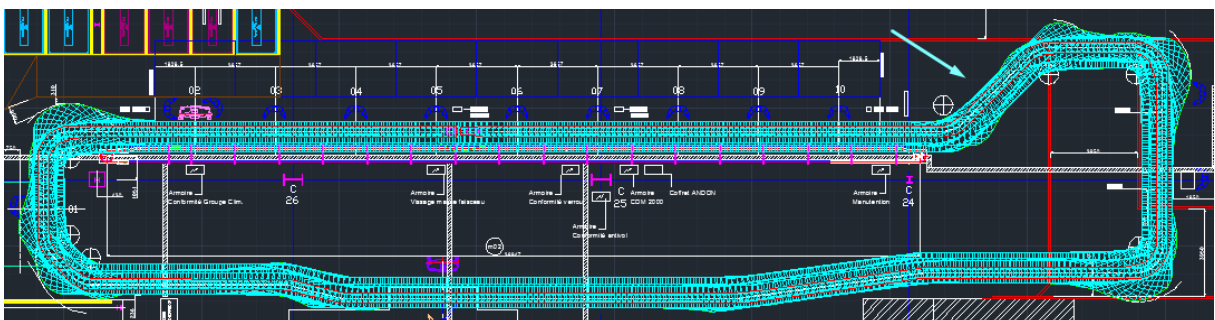
In the last received project, there were no problems and the vehicle was able to perform the entire route defined by the client. In the Figure 68 we can see the image of vehicle sweeps.



**Figure 68 - Sweep path analysis for the third client 1**

In Figure 68 it can be seen five lines to describe the path of the vehicle. Starting with the white one, that was the path that the client predicted, then by using Autodesk vehicle tracking we choose the vehicle that will have to perform that route, and the program will displayed the green and the red lines. The green lines represent the outer lines of the body of the vehicle, while the red line represents the path of the wheels.

In the Figure 69 it is shown the same path for an easier view. It is displayed with a navy blue colour.

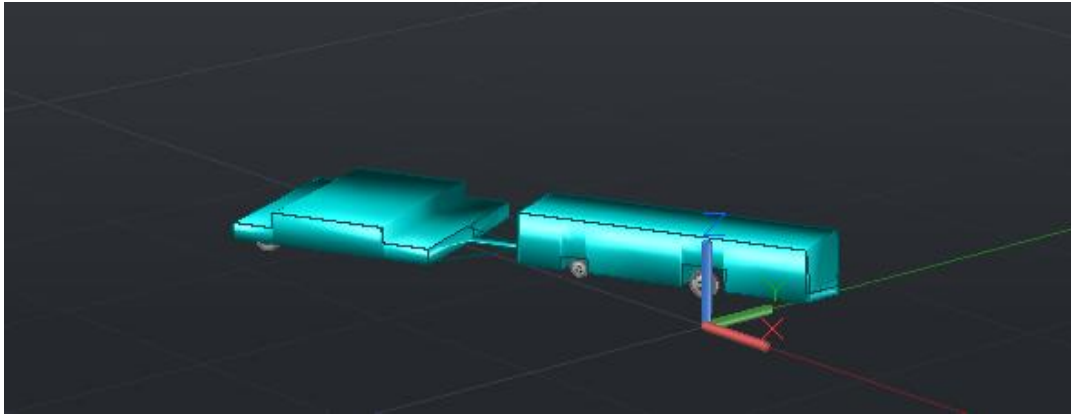


**Figure 69 - Sweep path analysis for the third client 2**

Both this images are integrated in Annex C and D, for an easier view.

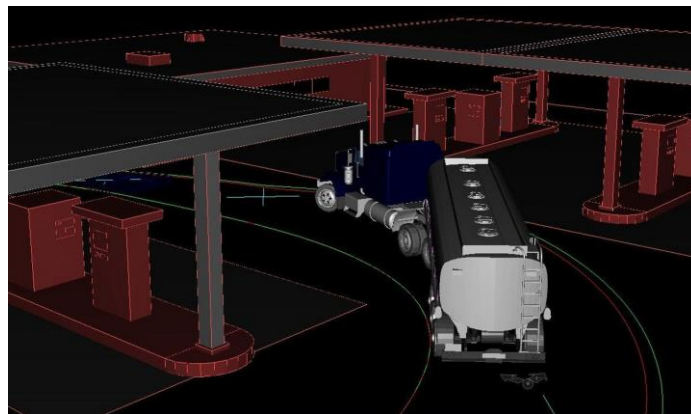
#### 4.4 Creation of simulations

Another important feature of this project was to be able to show to the client a simulation of the behaviour of the vehicle. This software program can simulate both in 2D and 3D. From Figure 68, in AutoCAD it can be created the 2D simulation of all the movement of the vehicle along the plant. The 3D simulation can be also created but is something that needs some improvements to adapt to the exact form of the vehicle.



**Figure 70 - Easybot & trailer 3D simulation**

As it can be seen in the 3D simulation of Figure 70, it is not as good as the real AGV, but it is something that it's still to be work on. In the Figure 71 we can see an example of this same program with a different vehicle and some studies will have to take in place in order to be able to achieve this level of detail.



**Figure 71 - Autodesk Vehicle tracking 3D simulation – adapted from <https://savoycomputing.wordpress.com/2013/06/>**

#### 4.5 Tags and sensor laser

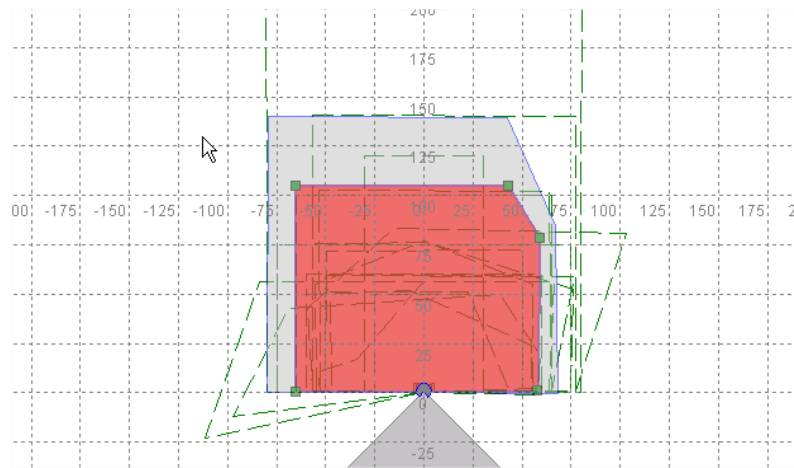
After the creation of the path, it can be defined two important features, the tag placement along the route and the definition of the sensor laser in the vehicle.

Before the program, the placement of tags was done manually, by trying to see where the vehicle RFID sensor would pass. This always generates two problems: first it was not very accurate since the human eye cannot know exactly the best point to place the tag, and the other reason was that this normally took a lot of time to know where to place each tag. Note

that in a circuit it is normal to have more than 10 tags. Normally without this software this would take two days of work in the client plant layout.

With this software we can simulate the position where the vehicle will pass and also any point that shares the same movement of the vehicle. By placing a tag in the middle of the RFID sensor and then by placing this point along the circuit we can know exactly where to insert the RFID tag in the circuit.

The other feature important to define is the sensor laser area. This area is defined along the path and it will change when the RFID sensor reads certain tags. It is important to define different sensor lasers since the vehicle needs to check different areas depending in the movement it is performing. For example, in a straight line we need to scan the front area to see if the vehicle can move through, but in a curve it is also important to check the inner corner to avoid the collision of the AGV. This also happens when the vehicle enters and exits a workstation. As it can see in the Figure 72, the sensor laser can have different shapes, and all of them are defined by the user. With this software we can also define the areas along the path which wasn't possible in the Kollmorgen software.



**Figure 72 - Sensor laser area 2**

## 5 Analysis and Discussion

In this chapter it will be discussed the advantages and disadvantages of the acquisition of the simulation software that motivated this project. The main disadvantage of the selected software is the price. There is the necessity for an initial investment in the software and every year on a new license. Even that we have this disadvantage, it only represents an investment which will generate an overall profit.

The implementation of this software brings a list of advantages for the company. The previous program could define route for just a few vehicles, but with this new software it can be simulated routes for more than 80% of the vehicles. Even when the route could be defined in the other program, its precision was poor, for two main reasons. The first one was that the mechanical system could not be well defined, and the other one is that the shape of the vehicle must be always a square, which is completely wrong, since only one vehicle have that kind of structure. With this new software it could be defined any shape for the vehicle and the mechanical behaviour of the vehicle has a quite good precision. Thanks to these improvements the route can be better defined.

This project also improved the system, by reducing the number of failures. One of them was the route placement in the client plant layout. Before the project, it was done totally by the personnel without any support of a software application. The personnel needed to create a route with the magnetic tape for example, and then test if the vehicle would be able to perform the desired route without any collisions and passing in the right positions for example in a workstation the vehicle must be parallel to it. By doing this without any support it could take up to two entire days, which isn't good because the costs to be working outside of the company (ASTI) are much higher. So with this software we could define the route and the magnetic tape at ASTI first and then when all the movement are exactly as we want it to perform, we can use it to tell the personnel where to place the magnetic tape so there will not have any problems in the client layout plant. The placement of the magnetic tape in the right position will reduce the time consumption by the personnel which will generate a reduce cost of it.

Thanks to the good precision of the software, another improvement was the placement of the tags along the route. Before this project, all the process was done by observing where the RFID sensor would pass and it was tested several times, until the AGV always read the tag without any failure. The problem of not knowing the exact position of where to place the tags is that it takes a lot of time to know the best position to place it. By knowing it, it will reduce working time and this will contribute to reduce the costs.

The route and tag placement before this project would take around two days of work outside of the company, with this project it would be reduced to just one.

So let's see exactly what where the improvements of this project and to where it leads:

- Improvement of the system – tag placement with bigger precision
- Routes better defined – thanks to the better definition of the vehicle shape and mechanics
- Reduced time of work – thanks to the support of a simulation software

- Reduced time of work outside of the company – the user now knows where he have to place the tags and magnetic tape
- Reduced costs – thanks to the reduced time of work outside of ASTI since it can be now done at ASTI
- Better knowledge of how the vehicle works and how the trailers will respond to a certain movement of the tractor unit
- And all this improvements will generate a better image of the company ASTI to the clients

There is also some estimation in relation to the type of projects.

**Table 8 - Improvement for each type of project**

Type of project	Phase	Number of hours before the project implemented	Number of estimated hours after the project	Improvement
1	Commercial	53	37	30.19%
1	Layout design	103	71	31.07%
2	Commercial	27	19	29.36%
2	Layout design	52	36	30.77%

**Table 9 - Project types**

	Project type 1	Project type 2
<b>N° of Easybot</b>	More than 15.	Until 15.
<b>N° of trailers</b>	More than 3.	Project with trailers that are not from type 1.
<b>Length of the vehicle + trailer</b>	More than 5m.	Less or equal to 5m.
<b>Other</b>	Vehicle dimensions are big in relation to the route.	Simulation of the vehicle and security areas that are not from type 1.

In Table 9 it is explained from the main characteristics of project types 1 and 2. Please take into account that if any characteristic belongs at project type 1, the project is of type 1, even that it has more characteristics of project type 2. For example, if there is a project with 14 Easybot and the number of trailers is 4, the project is type 1. A project is just of type 2, when there isn't any characteristic of the project type 1.

## 6 Conclusions

This project has explored the analysis of simulating the automated guided vehicles sweeps and, from this study, some conclusions emerged.

Firstly it was clear that, more important than software that simulates the sweeps of a vehicle, there is the necessity to understand the mechanical structure of a vehicle. To understand which are the important features in the mechanism that we need to take into account in the movement generation.

Before selecting a program is important to check if it is able to function with most of the vehicles that the company uses, and compare it with other market solutions. Nevertheless it's important to study the functions that the software must have, and also to know which programs it integrates with. Since it is a program to draw the sweeps of the vehicles, and the clients usually bring the format of the plant layouts in AutoCAD, it is really important that the program can be integrated with it.

Another important feature is to compare the error between the simulations with the reality; the chosen program had a maximum error of 3cm, which is quite good.

A good sweep path simulation, the possibility to add RFID tags along the path and the possibility to define sensor laser areas for more than 80% of the vehicles of the company are very positive factors that confirm the choice of the software.

In relation to the image to the client of a company that uses this type of program, it shows a good image by being able to show a simulation on the client plant, and together it can be discussed which is the better way to define the routes and to check which vehicles can make a specific route. The ability to check if the vehicle will have collision with any part of the plant is something more and more important in these days.

Since this type of companies have an internationalization mindset, it is important that they can plan everything before they install this type of AGV solutions in the client layout, because it will transmit a good image of the provider company. A good image in relation to the marketing because the client will be able to see the simulations; and a good image in terms of efficiency because the reduced time of installing the AGV solution in the client plant.

## 7 Future research

In every project there is always the necessity of improvement. For this one there are three important improvements that should take into account:

- Link Autodesk vehicle tracking with SIGAT
- Automatically create an AGV
- 3D view

The connection of SIGAT with Autodesk vehicle tracking is important because SIGAT is a database where there are all the RFID tags for each project and each vehicle. By having this connection, the coordinates of the RFID tags could be transmitted to the SIGAT database by the help of a macro.

The automatic creation of an AGV is a way to speed up and reduce the error in the creation of the vehicle. With the help of Excel the user will define which is the vehicle he wants to create from a dropdown menu and, depending on the chosen vehicle he will be able to select some specific dimensions. Then, Excel will create a file with the vehicle dimensions. This feature is to be inserted in the program.

The third improvement proposed is the ability to create in a 3D view vehicles as close as possible to the real ones. This is not very important in the department that creates and studies the routes, but it will be very important in the department of marketing, since it will transmit a good image of the company to the clients.

**Note:** SIGAT it's one software application programed by ASTI and it permits the configuration and supervision of the EASYBOT AGVs system.

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**ANEXX A: Software benchmarking parameters**

Price/License
Cost per license?
Necessity to have an annual cost of the license?
Difficulty to use the software
Hard
Normal
Easy
Necessity of formation
Cost of the formation?
Necessity to know other software programs?
Services
Direct integration with AutoCAD?
Possibility to export in AutoCAD format the vehicle sweep?
Possibility for 3D representation?
Vertical and horizontal vehicle sweep study?
Vehicle definition
Possibility to create different type of vehicles?
Possibility to create different type of vehicle libraries?
Can be defined points outside of the vehicle and study its trajectory?
How many points can be defined in a vehicle?
Can be defined an Easybot Standard?
Can be defined an Easybot Basic?
Can be defined a bidirectional vehicle?
Can be defined an omnidirectional vehicle?
What are the limits of axis in a vehicle and trailers? (Maximum and minimum)
Minimum and maximum time of block (by the variation of direction)?
Minimum and maximum angle of rotation of tractor unit?
Possibility to refine a vehicle with the exact dimensions of a real one?
Which details can be added? (Colour...)
Which parameters are needed to define the tractor unit?
Possibility to add trailers?

Maximum number of trailers?
Type of connection with trailers?
Maximum and minimum angle of the trailer unit?
Which parameters are needed to define the trailer unit?
<b>Sweep path</b>
Possibility to make a vehicle follow a determinate route?
Possibility to edit a defined route?
Possibility to use the same route to a different vehicle?
Maximum and minimum velocity in the route?
Velocity precision that can be assigned to the route?
Can be defined one exit line and an entry line, so the program calculates automatically the curve?
Can it be calculated the minimum radius of rotation?
Possibility to define layers as obstacles?
Possibility to define a safety zone around the vehicle?
<b>Simulations</b>
Possibility to create simulations?
Possibility to add different vehicle sweeps in the same simulation?
Possibility to control the stop instants and the variation of the velocity?
Possibility to control the camera of the simulation during the simulation?
Which type of effects can be added to generate a video? (Zoom, pan, follow...)
Possibility to create a video file?
Which formats?
<b>Support</b>
Time to reply
Quality

**ANEXX B: Final Program comparison**

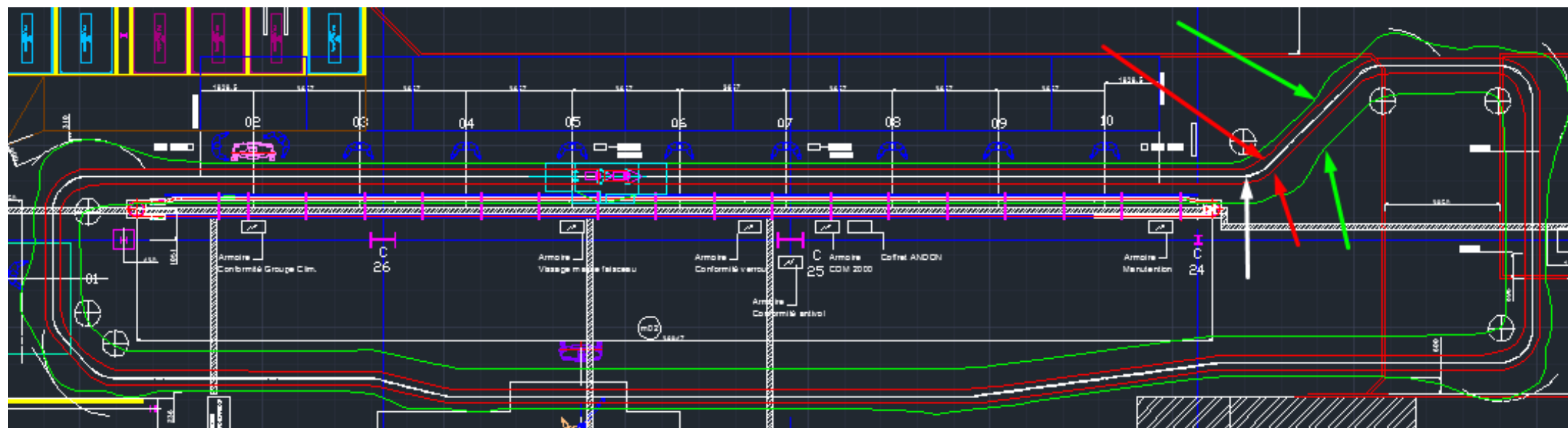
Program	Autodesk vehicle tracking	Auto turn 2D	Auto turn 3D	Invision
Website	<a href="#">WEBSITE</a>	<a href="#">WEBSITE</a>	<a href="#">WEBSITE</a>	<a href="#">WEBSITE</a>
Price/License				
Cost per license?	1.050 €	1.500 €	1.875 €	375 €
Necessity to have an annual cost of the license?	315 €	345	440	0
Difficulty to use the software				
Hard				
Normal				
Easy	Yes	Yes	Yes	Yes
Necessity of formation				
Cost of the formation?	No	Yes		Yes
Necessity to know other software programs?	Yes	Yes	Yes	No
Services				
Direct integration with AutoCAD?	Yes	Yes	Yes	<b>Yes</b>
Possibility to export in AutoCAD format the vehicle sweep?	Yes	Yes	Yes	NA
Possibility for 3D representation?	Yes	No	Yes	NA
Vertical and horizontal vehicle sweep study?	Yes	No	Yes	NA
Vehicle definition				
Possibility to create different type of vehicles?	Yes	Yes	Yes	NA
Possibility to create different type of vehicle libraries?	Yes	Yes	Yes	NA
Can be defined points outside of the vehicle and study its trajectory? How many points can be defined in a vehicle?	Yes	Yes	Yes	NA
Can be defined an Easybot Standard?	Yes	Yes	Yes	NA

Can be defined an Easybot Basic?	Yes	Yes	Yes	NA
Can be defined a bidirectional vehicle?	No	No	No	NA
Can be defined an omnidirectional vehicle?	No	No	No	NA
What are the limits of axis in a vehicle and trailers? (Maximum and minimum)	1 to 20	1 to 15	1 to 15	NA
Minimum and maximum time of block (by the variation of direction)?	$\geq 0,1$	3 to 20	3 to 20	NA
Minimum and maximum angle of rotation of tractor unit?	$\geq 0$	1 to 80	1 to 80	NA
Possibility to refine a vehicle with the exact dimensions of a real one? Which details can be added? (Colour...)	Yes	No	Yes	NA
Which parameters are needed to define the tractor unit?				NA
Possibility to add trailers?	Yes	Yes	Yes	NA
Maximum number of trailers?	6	18	18	NA
Type of connection with trailers?				NA
Maximum and minimum angle of the trailer unit?	$\geq 0$	1 to 90	1 to 90	NA
Which parameters are needed to define the trailer unit?				
<b>Sweep path</b>				
Possibility to make a vehicle follow a determinate route?	Yes	Yes	Yes	NA
Possibility to edit a defined route?	Yes	Yes	No	
Possibility to use the same route to a different vehicle?	Yes	Yes	Yes	
Maximum and minimum velocity in the route? Velocity precision that can be assigned to the route?	$\geq 0$	1 to 38	1 to 38	
Can be defined one exit line and an entry line, so the program calculates automatically the curve?	Yes	No	No	
Can it be calculated the minimum radius of rotation?	No	Yes	Yes	
Possibility to define layers as obstacles?	Yes	Yes	Yes	
Possibility to define a safety zone around the vehicle?	Yes	Yes	Yes	
<b>Simulations</b>				
Possibility to create simulations?	Yes	Yes	Yes	Yes
Possibility to add different vehicle sweeps in the same simulation?	Yes	No	No	Yes
Possibility to control the stop instants and the variation of the velocity?	Some points	No	No	Yes

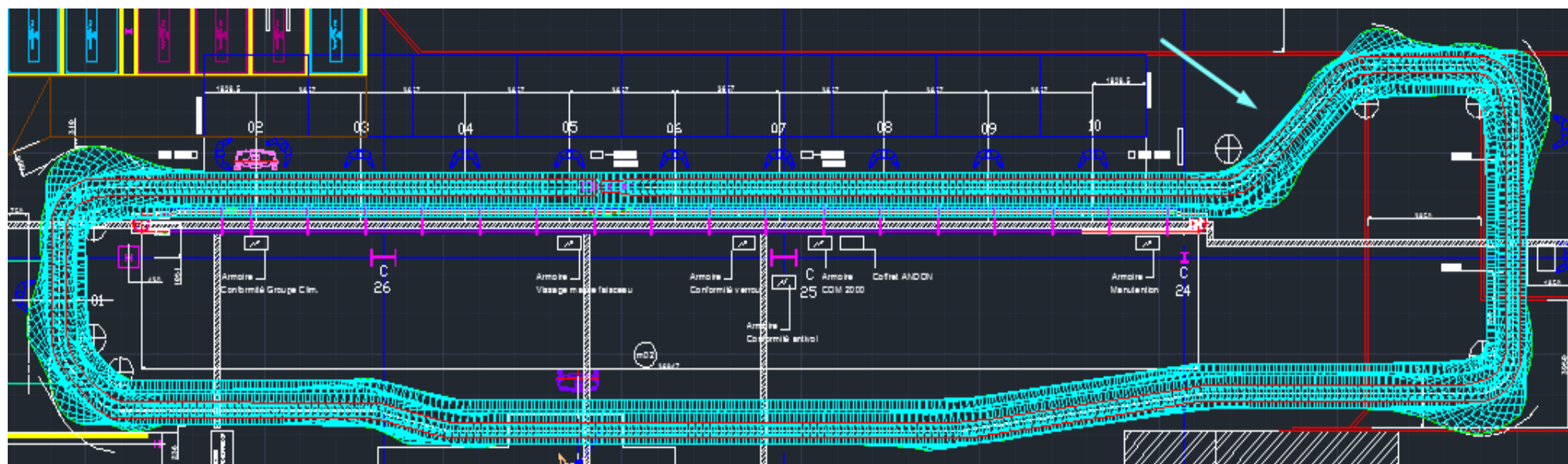
Possibility to control the camera of the simulation during the simulation?	Yes	Yes	Yes	Yes
Which type of effects can be added to generate a video? (Zoom, pan, follow...)				
Possibility to create a video file? Which formats?	AVI	No	No	AVI
System requirements	<a href="#">Website</a>	<a href="#">WEBSITE</a>	<a href="#">WEBSITE</a>	<a href="#">WEBSITE</a>
Support				
Time of reply	Slow	Fast	Fast	Fast
Quality	Medium	Good	Good	Medium

NA - Stands for Not Applicable

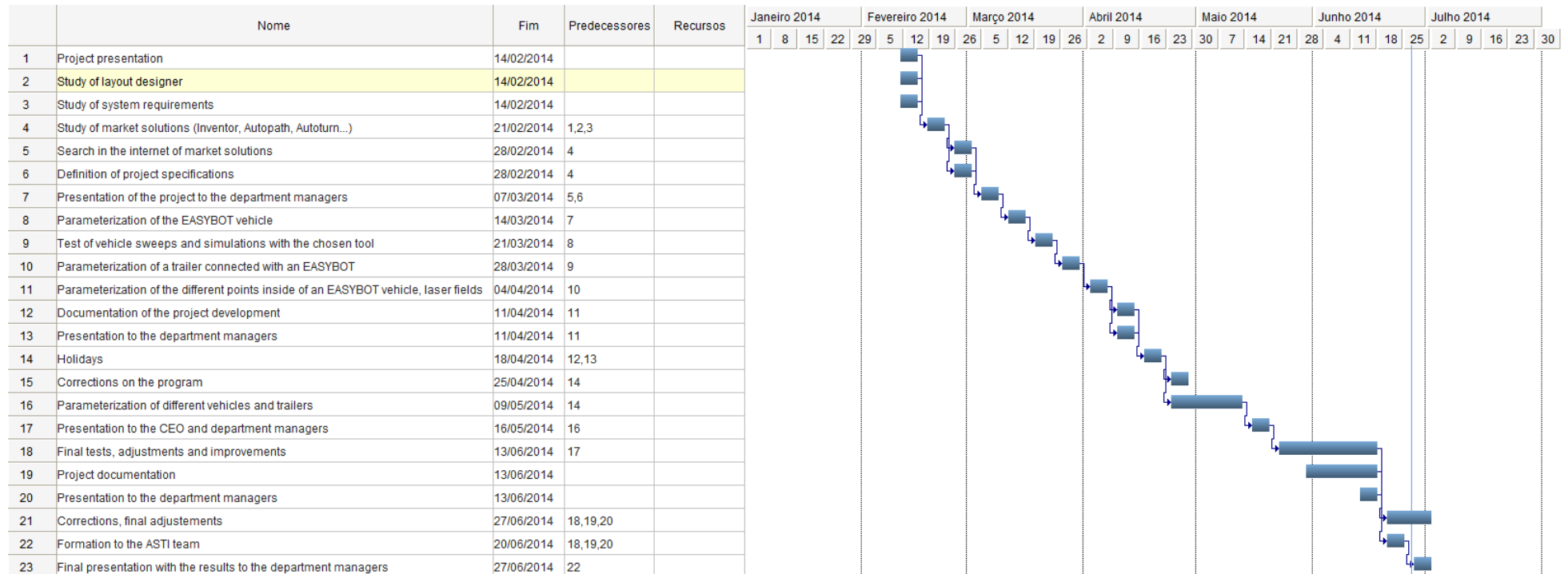
## ANEXX C: Route layout 1



## ANEXX D: Route layout 2




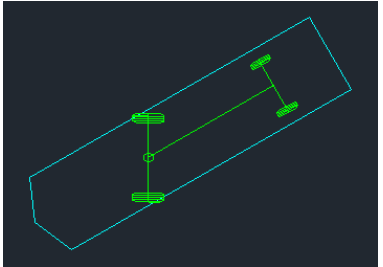
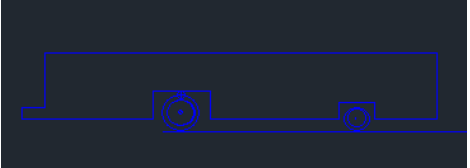
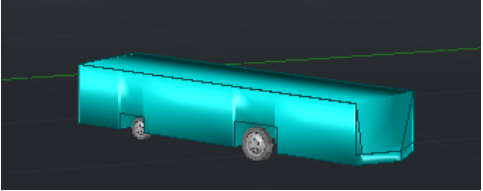



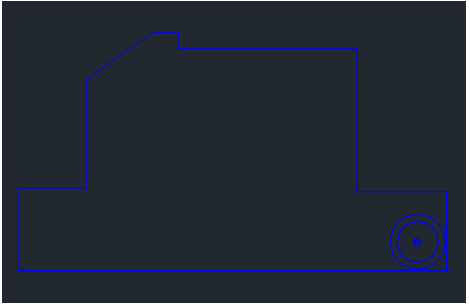
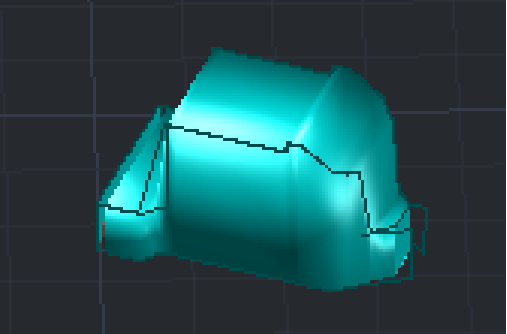




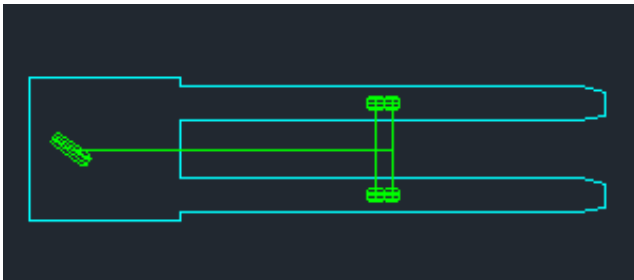



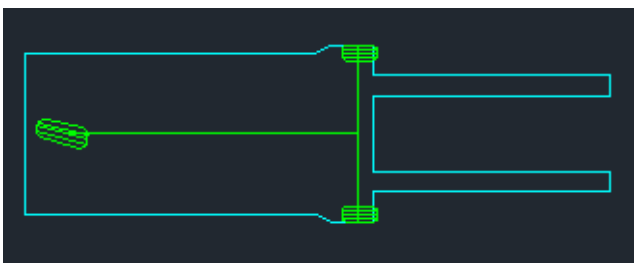
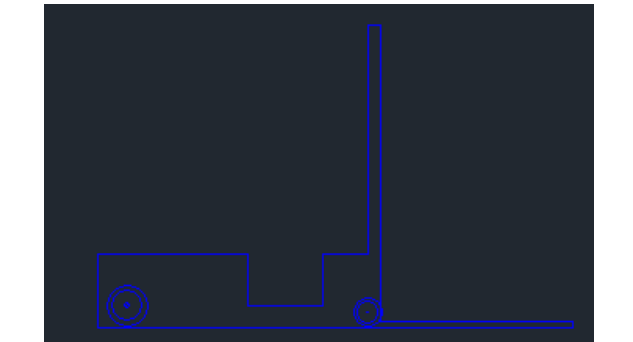


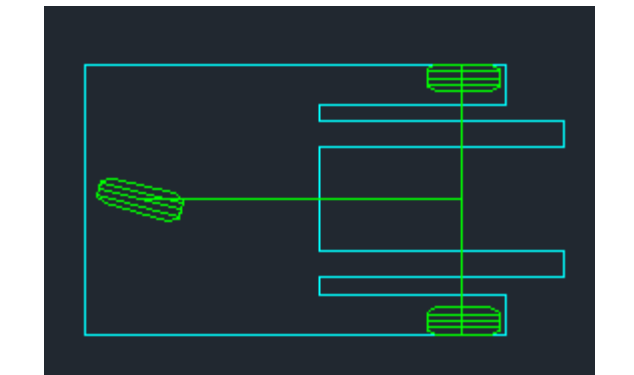
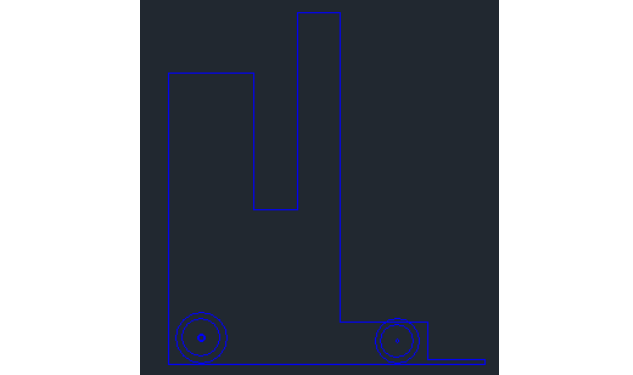
## ANEXX E: Gantt diagram



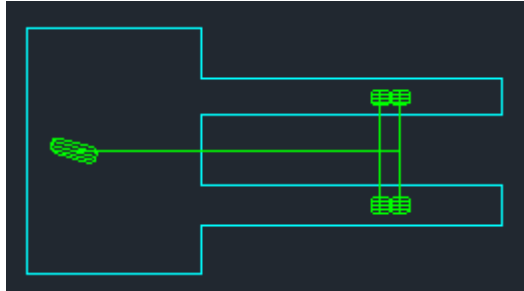
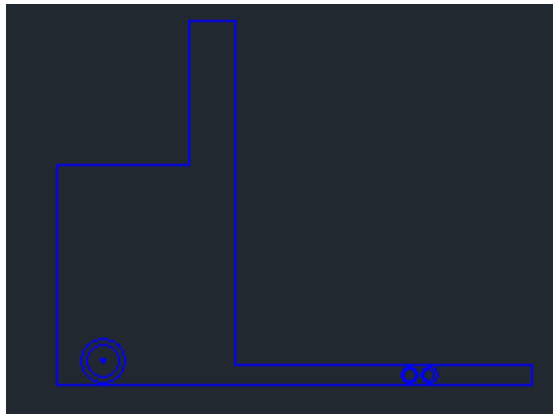


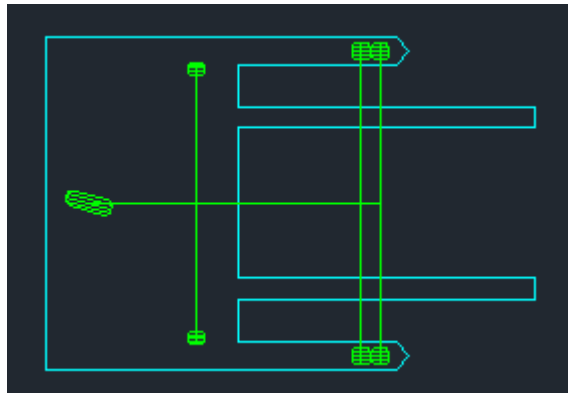
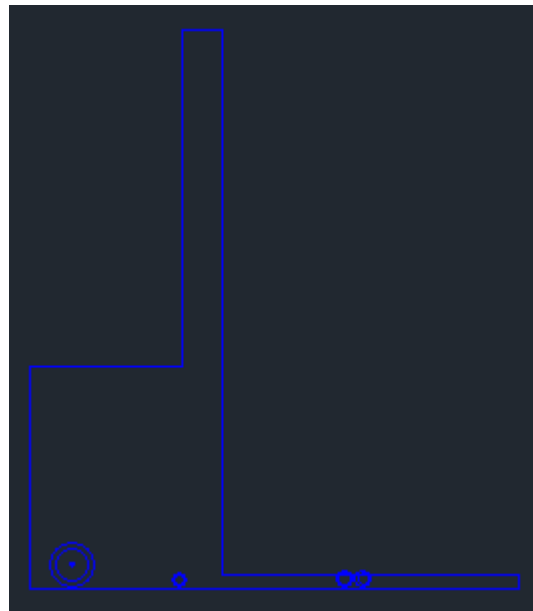




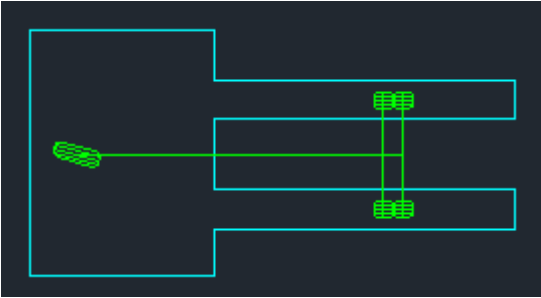
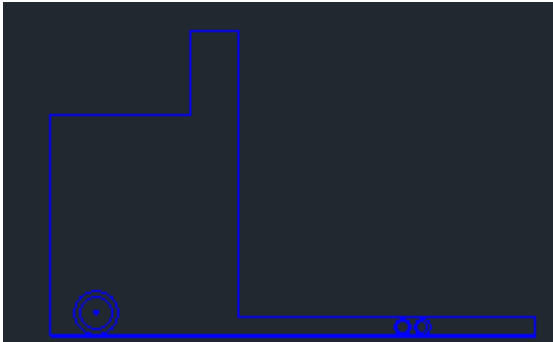


## ANEXX F1: Created vehicles – One unit





Vehicle in the library	Horizontal image	Vertical image	3D image
 EASYBOT  EASYBOT Tractor  EASYBOT Body			
 EASYBOT Basic  EASYBOT Basic Tractor			

Vehicle in the library	Horizontal image	Vertical image
 LPE 240_620Ah_y-1811_I-2350_b5-685  LPE 240_620Ah_y-1811_I-2350_b5-685 Unidad tractora		
 OSE120CB_h1-1841_b5-570  OSE120CB_h1-1841_b5-570 Unidad tractora		
 RRE200_620Ah_h1-2732_I-1150_b5-738_b4-900_I4-670  RRE200_620Ah_h1-2732_I-1150_b5-738_b4-900_I4-670 ...		

Vehicle in the library	Horizontal image	Vertical image
<p>  SPE125_430Ah_Duplex_b1-1150_l-1400_b5-685_h1-2365   SPE125_430Ah_Duplex_b1-1150_l-1400_b5-685_h1-236... </p>		
<p>  SPE135S_b_l-1400_b2-1560_b4-1300_b5-900   SPE135S_b_l-1400_b2-1560_b4-1300_b5-900 Unidad tr... </p>		

Vehicle in the library	Horizontal image	Vertical image
 SPE160_Duplex_b1-1150_I-1400_b5-685_h1-2405  SPE160_Duplex_b1-1150_I-1400_b5-685_h1-2405 Tract...		

**ANEXX F2: Created vehicles – Vehicle and trailer**

Vehicle in the library	Horizontal image	3D image
 EASYBOT_Nt-1_Ns1 <ul style="list-style-type: none"> <li> EASYBOT_Nt-1_Ns1 Tractor</li> <li> EASYBOT_Nt-1_Ns1 Body</li> <li> EASYBOT_Nt-1_Ns1 Trailer 1</li> </ul>	